INSTREAM AND LABORATORY EVALUATIONS

of

THE TOXICITY OF CHLORINATED MUNICIPAL WASTEWATERS

by

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Technical Services Branch Biomonitoring Project No. 88-04
May, 1990

COMMONWEALTH OF MASSACHUSETTS

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PUBLICATION #16,379-147-25-7-90-C.R.
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TITLE: Instream and Laboratory Evaluations of the Toxicity of Chlorinated Municipal Wastewaters

DATE: May 31, 1989

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FOREWORD

The Massachusetts Division of Water Pollution Control was established by the Massachusetts Clean Water Act, Chapter 21 of the General Laws as amended by Chapter 685 of the Acts of 1966. Included in the duties and responsibilities of the Division is the periodic examination of the water quality of various coastal waters, rivers, streams, ponds, wetlands and groundwaters of the Commonwealth, as stated in section 27, paragraph 5 of the Acts. This section further directs the Division to publish the results of such examination together with the standards of water quality established for the various waters. One of the responsibilities of the Technical Services Branch of the Division of Water Pollution Control is the execution of this directive. This report is published under the Authority of the Acts and is among a continuing series of reports issued by the Division presenting water quality data and analyses, water quality management plans, baseline and intensive limnological studies and various special studies.

EXECUTIVE SUMMARY

Background

This report presents several case studies concerning the toxic effects of chlorinated wastewaters on freshwater aquatic life. These studies were conducted to address certain issues in the development of permit limits for the use of chlorine in wastewater disinfection. The procedures and experiments described in this report were designed to help answer the following questions:

1. What are the magnitude and extent of toxic impacts caused by chlorinated municipal discharges to streams in Massachusetts?

2. What chlorine concentrations cause acute effects to aquatic organisms under field conditions?

3. Can the results of chlorine-dosed effluent toxicity tests conducted in the laboratory be used to predict instream impacts?

4. What relationship exists between the toxicity of TRC observed in field studies and the promulgated EPA acute criterion (0.019 µg/L TRC) for chlorine?

5. Can the procedures developed in conducting these instream investigations be used as a practical tool by regulators to generate site-specific chlorine limits in lieu of criteria-based limits?

Methods

During the months of July, August and September, 1988, five concurrent laboratory and field studies of chlorine toxicity were conducted at three wastewater treatment plants (WWTPs): the Westborough-Shrewsbury, Belchertown and Hopedale plants. The field component of these evaluations consisted of instream survival tests with caged fathead minnows (Pimephales promelas) which were conducted over two consecutive 24-hour periods. Total residual chlorine (TRC) was measured at control (upstream of the discharge), effluent, and test stations (downstream of the discharge) at 2-3 hour intervals throughout the test period to assess exposure levels. In addition, effluents and receiving streams were evaluated for an array of chemical parameters including routine parameters such as dissolved oxygen, temperature and pH, as well as a variety of metals, nutrients and organics. The instream waste concentration (IWC, defined as the proportion of the receiving stream that is composed of effluent) of each effluent was determined for each study through chloride analyses of 24-hr. composite samples of effluents and receiving streams.

Forty-eight hour static acute toxicity tests were run in the laboratory on both unchlorinated and chlorine-dosed 24-hour composite samples of effluents collected while each field study was in progress. Chlorine dose-response relationships were established for each effluent sample using three test species: the fathead minnow, and the two cladocerans, Daphnia pulex and Ceriodaphnia dubia.

Data generated in the field and laboratory were compared and evaluated against the fathead minnow species mean acute value for TRC (105 µg/L) derived by EPA (1986) and the EPA water quality acute criterion for chlorine of 19 µg/L TRC.

Results

None of the unchlorinated wastewater samples were toxic to laboratory test organisms. In addition, survival of caged fathead minnows held at control stations upstream of WWTP discharges was high (≥85%) in all five studies. These two findings established that instream impacts to caged minnows were due to wastewater chlorination rather than to other toxic components of effluents or to pollutant discharges to streams under study other than those from the WWTPs being evaluated.

Caged minnows deployed downstream of chlorinated discharges were adversely impacted in all five studies. The zone of impact was small at the Westborough site but extensive at the Belchertown and Hopedale sites.

At the Westborough site, 24-hr acute effects to minnows were only observed at the first test station, 21 m downstream of the confluence of the effluent with the receiving stream. Downstream of this station, minnows withstood TRC concentrations in excess of the EPA fathead minnow species mean acute value for over 15 hours and withstood pulses of 350 µg/L TRC for short periods.

At the Belchertown site, instream TRC concentrations in excess of 30 µg/L killed 100% of the minnows on one study, and TRC concentrations in excess of 95 µg/L killed 100% of the minnows on the second study. Stress due to low ambient dissolved oxygen and a possible interactive effect due to ammonia-nitrogen may have increased the sensitivity of minnows to TRC toxicity at the Belchertown site. TRC levels of 30 µg/L are approximately 70% lower than the fathead minnow species acute value and approach the EPA acute criterion level of 19 µg/L TRC.

The Hopedale site was the most impacted in terms of total stream distance. An uncontrolled, short duration pulse of TRC was associated with minnow mortality throughout the study area (508 m) at this site.

The instream waste concentration (IWC) of effluents ranged from 25 to 86% of the total stream flow in each of the studies.

The laboratory chlorine toxicity tests, on the whole, were inconsistent predictors of the instream impacts recorded in the field studies with caged minnows. The laboratory minnow tests both over- and underestimated TRC concentrations associated with mortalities found instream. Throughout all the laboratory studies, the relative sensitivity of the three test species was consistent with _Ceriodaphnia dubia_ being most sensitive followed by _D. pulex_ and the fathead minnow.

Concentrations of TRC discharged to receiving waters were highly variable within and between the three study locations. Extremes ranging from 0.33 mg/L to 2.9 mg/L TRC were recorded over a period of 48 hours at one site alone. Poor control of effluent TRC appears to be a common problem and is probably related to the mechanics of chlorination as well as plant flow variability and changing wastewater chemistry.

The methods used in these studies appear to be useful for documenting the zone of 24-hr acute impacts of TRC to fathead minnows in the field. Data generated from these studies could not, however, be used to generate site-specific TRC limits for the plants that were evaluated. This is due to the high degree of variability in effluent TRC concentrations over each study which precludes the development of clear dose-response relationships between TRC and test organism mortality.

The authors feel that the most judicious approach to the development of TRC limits for chlorinated wastewaters is to require dechlorination or alternate disinfection for facilities with IWCs of 10% or greater. In situations where the IWC is lower, facilities could be given the option of either meeting the EPA criteria or providing documentation from instream studies that acute effects in receiving streams do not exist due to the chlorination of wastewaters. The 10% IWC level was chosen because effluent TRC concentrations of at least 0.5 to 1.0 mg/L (and 15 min. contact time) are needed to achieve adequate kill of fecal coliforms in secondary effluents according to operators surveyed in this study. TRC concentrations in areas where the IWC is 10% would thereby range, at a minimum, from 50 to 100 µg/L. Actual instream levels would occasionaly be much higher due to unplanned TRC excursions. The authors feel that under these conditions there is a high probability of producing adverse impacts to biota and a blanket policy requiring dechlorination or alternate disinfection is appropriate for these high-risk situations.

The authors recommend that if the field methods are to be used on a routine basis to evaluate short-term acute effects of TRC, a number of changes should be made. These are outlined in the full report and emphasize streamlining of field and laboratory analyses.

Recommendations

Based on the investigations conducted during the summer of 1988, the authors feel that aquatic biota are at risk in many of the streams in Massachusetts due to chlorine toxicity. Factors contributing to this conclusion are the level of acute instream impacts observed in these studies due to wastewater chlorination, and the lack of adequate chlorine control at WWTPs. In addition, both chlorine dissipation and toxicity were found to be highly variable in these studies. These two parameters can affect the intensity and areal extent of impacts due to TRC and have been linked to effluent chemistry which may vary dramatically over the normal course of operation at WWTPs.

Wastewater facilities posing the greatest threat to aquatic communities in receiving streams are those with a high IWC. In order to provide protection for those streams most severely impacted by chlorinated discharges, the authors recommend that facilities with an IWC of 10% or greater should either dechlorinate or use an alternate form of disinfection. In higher dilution situations where site-specific conditions do not allow for a zone of passage, or where there is specific knowlege of a sensitive community, the authors also recommend dechlorination or alternate disinfection. In those situations where the IWC is less than 10% but instream levels of TRC exceed the criteria, the authors suggest that facilities be given the option of either complying with the criteria, or providing evidence that there are no acute TRC effects to the aquatic community through an instream evaluation conducted under low flow conditions.

ACKNOWLEDGMENTS

The Massachusetts Department of Environmental Protection's Lawrence Experiment Station performed nearly all the chemical analyses of water and wastewater samples. Total organic carbon analyses were performed by a U.S. Environmental Protection Agency (EPA) contract laboratory.

Robert Nuzzo, Division of Water Pollution Control (DWPC), came up with the idea of using discarded soft drink bottles to protect minnows deployed instream from excessive water velocities. Edward Gritsavage, U.S. EPA, assisted in the laboratory toxicity analyses.

The authors extend their thanks to these institutions and individuals as well as the personnel from DWPC, EPA and the private sector who assisted in the field and laboratory work for this project. Special thanks go to Polly Delaney of DWPC who typed the appendices to this report.

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INTRODUCTION

Chlorine is used in all but four of the publicly-owned wastewater treatment plants in the Commonwealth of Massachusetts as a disinfectant to control the spread of human pathogens. Over the past several years, personnel from the Massachusetts Division of Water Pollution Control (DWPC) and the Federal Environmental Protection Agency (EPA) have been involved in discussions pertaining to the development of effluent limits for chlorinated wastewaters. The two agencies are jointly responsible for the development and enforcement of wastewater permits in the Commonwealth.

The central issue of these discussions has been the problem of protecting aquatic organisms from the toxic effects of chlorine while still maintaining adequate disinfection of wastewaters. EPA water quality criteria (EPA 1984a) specify that in order to protect aquatic biota from acute effects, a one-hour average instream level of 0.019 mg/L total residual chlorine (TRC) should not be exceeded for more than one hour every three years. DWPC policy, however, recommends that in order to provide adequate kill of human pathogens, the concentration of TRC in municipal wastewater discharges after 15 minutes of contact with chlorine should be between 0.5 and 1.5 mg/L. In order to satisfy both these requirements, most sewage treatment plants in the state would have to either dechlorinate their effluents or employ an alternate form of disinfection.

In considering the expense involved in applying the EPA acute chlorine criterion in all cases, individuals from DWPC questioned whether or not instream impacts relating to the chlorination of wastewaters could be documented. A number of facts concerning both the nature of chlorine as well as the derivation of the EPA criterion conflicted with the view that instream TRC concentrations above the criterion level would always result in impacts to aquatic organisms in the receiving stream.

First, the chlorine acute criterion was derived primarily from the results of laboratory studies. It is possible that field conditions could significantly alter the toxicity of chlorine to the degree that the criterion level would be overly protective at most locations. Second, chlorine is a non-conservative pollutant. That is, upon contact with an aqueous medium, under normal conditions of pH, the concentration of chlorine will decrease over time. Degradation rates of chlorine are known to vary dramatically due to a number of factors including temperature, ammonia concentration, light intensity and organic content of a water sample. Water quality engineers working with chlorinated wastewaters expressed the opinion that chlorine decomposes rapidly and is rendered harmless soon after the effluent stream leaves the chlorine contact chamber. The toxic effects of chlorine in the field would thereby be limited to a very small zone of influence.

For a short time, the two agencies investigated the use of laboratory toxicity tests to set TRC limits in permits rather than applying the EPA acute chlorine criterion in all situations. Sewage treatment facilities were given the option of either meeting the EPA criterion or conducting both unchlorinated and chlorine-dosed effluent toxicity tests to characterize the toxic effects of chlorine in the effluent. Results of these tests were to be used in adjusting permit limits for TRC at sewage treatment plants on a site-specific basis.

After reviewing a substantial number of data reports from consultants conducting these tests, biologists from the two agencies questioned the utility of these test results in setting permit limits for chlorine. First, LC_{50}s from these tests were sometimes spread over a wide range for any particular facility. Second, there was a low degree of confidence in the quality of the chlorine data sets from these reports. In addition, individuals from both agencies began to question whether or not the chlorine-dosed toxicity tests, even under well controlled conditions, could be used to predict the impacts of TRC on aquatic organisms under field conditions. The uncertainties surrounding the behavior of chlorine and its toxicity under various conditions prohibited the two agencies from coming to agreement on a permitting policy.

The experiments described in this report were a result of meetings between the two agencies and were designed to answer the following questions:

1. What are the toxic impacts of chlorinated municipal wastewater discharges to receiving waters in Massachusetts and how extensive are these impacts beyond the initial zone of mixing?

2. What concentrations of TRC cause acute effects to aquatic organisms under field conditions?

3. Can the results of chlorine-dosed effluent toxicity tests conducted in the laboratory be used to predict instream impacts due to chlorine?

4. What relationship exists between the toxicity of TRC observed in field studies and the promulgated EPA acute criterion for chlorine?

5. Can the procedures developed for conducting these instream investigations be used as a practical tool by regulators to generate site-specific chlorine limits in lieu of criteria-based limits?

During the summer and fall of 1988, personnel from the DWPC Technical Services Branch office and the EPA New England Regional Laboratory conducted a series of studies to address these questions. Three municipal wastewater treatment plants (WWTPs) with chlorinated effluent discharges to streams in Massachusetts were selected for study. At each of these sites, 24-hour survivorship studies with caged fathead minnows (Pimephales promelas) were conducted to evaluate the degree and extent of the toxic effects of each discharge. Instream levels of TRC were monitored over the course of these studies at stations where minnows were deployed. Minnow survival at each station was then compared with TRC concentrations at each station.

Data from diel water column TRC measurements and associated field mortalities of minnows were compared with the EPA (1984a) species mean acute value for fathead minnows (i.e., 105 µg/L TRC). This value is well above the 19 µg/L freshwater acute criterion established by EPA for protection of freshwater aquatic life. Although a number of smaller aquatic organisms, such as daphnids and ceriodaphnids, are known to be more sensitive to TRC than fathead minnows, the latter were chosen for study primarily due to limitations imposed by the field equipment which restricted the range of test organism size. If field studies demonstrated that fathead minnows could withstand TRC concentrations much higher than the 105 µg/L level reported in the criteria document, this would be interpreted as evidence that field conditions significantly lowered the toxicity of TRC to minnows.

Laboratory toxicity studies were conducted on both chlorinated and unchlorinated wastewater samples to separate the effects of chlorine from potential toxic effects of other components of the wastewater. Fathead minnows, and two cladocerans, *Daphnia pulex* and *Ceriodaphnia dubia*, were used in the laboratory evaluations of effluents. Results of the laboratory tests with fathead minnows were compared with those of the instream studies to determine the usefulness of the former in predicting instream effects. Results of the laboratory toxicity tests with the other species were compared with those run on fathead minnows to evaluate differences in the sensitivity of the three species to TRC toxicity.

SITE SELECTION CRITERIA AND SITE DESCRIPTIONS

Background

The selection of study sites was based on a number of criteria. To avoid confounding the effects of chlorine with those of other potential toxicants in wastewaters, the investigators excluded facilities receiving substantial industrial inputs from the list of potential sites. Those plants with a history of toxicity problems not related to chlorine were also excluded. Preliminary screening tests with *D. pulex* and *P. promelas* were conducted on unchlorinated effluent grab samples from candidate facilities prior to the final selection of sites. These were conducted to maximize the potential for studying wastewaters that were free from toxic effects to test organisms other than those due to chlorine.

Field studies were biased towards facilities with estimated instream waste concentrations (IWC) of 20 percent or greater at 7Q10 (where IWC is defined as [effluent flow]/[effluent flow + river flow]). This helped to limit the study to situations in which worst-case conditions of instream chlorine toxicity might be found. In addition, over the duration of each instream study an attempt was made to maintain an effluent TRC concentration of 1.0 mg/L which was the typical level maintained at most plants in Massachusetts. By specifying these conditions, the investigators expected instream TRC values near the point of discharge to exceed the EPA acute criterion by at least an order of magnitude if the field studies were conducted during periods of low flow.

The three plants chosen for study are all publicly-owned municipal sewage treatment plants located in central Massachusetts. They are described in the chronological order in which they were evaluated. Throughout this report the terms control and test stations will be used to refer, respectively, to instream stations located upstream and downstream of the effluent discharge.

Westborough-Shrewsbury WWTP: The Westborough-Shrewsbury facility employs an activated sludge process and achieves advanced treatment (ammonia removal) through oxidation. The effluent travels through sand filters prior to disinfection by sodium hypochlorite. Chlorine addition to the effluent was manually operated over the period of these evaluations as the flow-paced chlorination unit usually used at this plant was not functional. After disinfection, the waste stream travels approximately 120 m through an effluent channel and enters the Assabet River. Design flow at the Westborough-Shrewsbury plant is 7.7 million gallons per day (MGD); dry-weather flow averages approximately 4.0 MGD.

The Assabet River in this area is a third order (using Strahler's 1952 nomenclature), slow-moving stream with a muddy bottom. Instream flow under 7Q10 conditions just upstream of the Westborough-Shrewsbury WWTP discharge is 2.2 MGD. The Assabet River is a part of the Concord River Basin and is classified by the DWPC (1983) as a warm-water fishery in the vicinity of the Westborough WWTP discharge. Maximum stream depth varied from approximately 0.5 m to 1.3 m over the study area. Stream width in this area ranged from 3 m to 12 m. Overhanging vegetation, especially grasses, shaded the stream in the area of the upper two test stations. The canopy opened up in the lower stretches of the study area and the stream was only partially shaded at the three test stations farthest from the discharge. The study area at this site extended to 536 m downstream of the confluence of the the WWTP discharge with the Assabet River.

The Assabet is tea-colored prior to mixing with the Westborough-Shrewsbury effluent, probably due to inputs of humic and fulvic substances originating from a swamp located approximately one mile upstream of the study site. The pH in this area ranged from 5.3 to 7.0 over the course of the two field studies. The wide variation in pH may have been related to a rain event which occurred on the second day of the field studies. Total hardness (Ca plus Mg) upstream of the Westborough-Shrewsbury discharge was 50 to 53 mg/L (as $CaCO_3$). The alkalinity (as $CaCO_3$) in this area ranges from approximately 20 to 50 mg/L (DWPC, 1988).

Belchertown WWTP: The Belchertown plant achieves secondary treatment through extended aeration. A series of lagoons receive the aerated waste and act as clarifiers. The final waste stream is dosed with sodium hypochlorite prior to release to Lampson Brook, a third order stream. The rate of chlorine addition to the wastewater is set manually at this plant. Design flow at the Belchertown plant is 0.5 MGD; average dry-weather flow is approximately 0.28 MGD.

Lampson Brook is located on the eastern side of the Connecticut River Basin. Instream flow under 7Q10 conditions is approximately 0.06 MGD upstream of the Belchertown WWTP discharge. At the test stations located closest to the discharge, the brook was shallow (approximately 0.3 m in the deepest spots) with sand/rubble/cobble substrates. At the two test stations farthest from the discharge, water depth was approximately 0.8 m; soft organic substrates predominated in this area. While the stream was well shaded by a canopy of trees at upper stations, it became completely covered by grasses as it flowed into a wetland where the last two stations were located. Stream widths varied from approximately 2 m to 4 m throughout the study area which extended to 244 m downstream of the WWTP discharge to Lampson Brook. The DWPC (1983) classified Lampson Brook as a warm-water fishery downstream of the Belchertown discharge; upstream reaches of this brook have not been classified by the Commonwealth.

The pH in Lampson Brook upstream of the area where it mixes with the Belchertown effluent ranged from 6.8 to 7.3 over the course of the two field studies. Total hardness in this area of the brook was 95 to 97 mg/L; alkalinity was 57 to 58 mg/L.

Hopedale WWTP: The Hopedale plant is an advanced waste-treatment facility. It has an activated sludge component and achieves phosphorus and ammonia removal by chemical precipitation and pH control in the primary clarifiers and the aeration tanks. The rate of chlorine addition to the effluent is manually adjusted at this facility. Plant design flow is 0.6 MGD; average dry-weather flow is approximately 0.4 MGD.

The receiving stream for the Hopedale effluent is the Mill River, a third order stream in the Blackstone River Basin with a 7Q10 flow of approximately 0.45 MGD immediately upstream of the Hopedale point of discharge. Substrates throughout the study area were coarse sand mixed with fine-grained organic materials. Maximum stream depths ranged from 0.3 m to approximately 1.2 m; stream widths varied from about 3 m to 9 m. Tree canopies shaded the stream throughout the study area which extended to 518 m downstream of the confluence of the effluent with the Mill River. The DWPC (1983) classified the Mill river as a cold water fishery in the vicinity of the Hopedale discharge.

The pH in the Mill River upstream of the point where it mixes with the Hopedale WWTP effluent ranged from 6.7 to 7.5 over the 24 hours of the field evaluation. Total hardness in this area of the river was 33 mg/L; alkalinity was 18 mg/L.

MATERIALS AND METHODS

Establishing Stations

Five field and laboratory studies were conducted: two at each of the Westborough and Belchertown sites and one at the Hopedale site. At each of the three sites, a number of instream stations were established prior to the initiation of each study. One control station, an effluent station and five to ten test stations were located at each site. Rhodamine dye studies were conducted to establish the extent of any effluent movement upstream as well as to establish the location of complete mixing of the effluent with the receiving stream.

Instream TRC evaluations conducted prior to each study were used to set test station locations. TRC was measured downstream of the effluent discharge, at intervals of approximately 100 meters, until non-detectable (<0.03 mg/L) TRC levels were encountered. One or two stations were set downstream of this point and the others were set between this point and the area of WWTP effluent entry to the receiving stream. The control station at each site was placed upstream of the effluent discharge to the receiving stream. Distance from the effluent to each station was measured by tape or TOKO™ (model 0610852) range finder.

Field Studies with Caged Minnows

To assess the instream effects of chlorinated effluents, field crews deployed caged fathead minnows, <u>Pimephales promelas</u>, at control and test stations. Minnows used in field studies were 8-14 days old and were obtained from the EPA Newtown, Ohio facility. Fish were acclimated (<1^{o} C change/hr.; maximum of 4^{o} C/day) to stream temperatures prior to study initiation. Timing of cage deployment was synchronized with the compositing of effluent samples so that the effluent passing over the instream minnow cages would approximate that used in the laboratory tests. Cages were left instream for 24 hours after which time the test was terminated and minnow survival was checked and recorded. Minnows not responding to gentle prodding were considered dead.

Minnow cages were a composite of two containers, one inside the other (see Figure 1). The inner container held the minnows and was made from 5 cm inner diameter acrylic plastic tube (plexiglass) with 0.5 mm mesh Nytex™ screen attached to each end following the design of O'Brien and Kettle (1981). The outer container was used to reduce the water velocity flowing through the inner cage and thus protect minnows from mechanical stress. Outer containers were constructed from perforated, 1-liter plastic soft-drink bottles with removable bottoms. After the inner cage was placed inside the outer container, the bottom of the latter was affixed and held in place with rubber bands and paper clips.

Two sets of cages with ten minnows per cage were deployed at all instream stations. The cages were oriented with the bottleneck upstream and wired between steel reinforcing rods pounded into the stream bottom. Cage depth was approximately 5-20 cm below the stream surface depending on the site.

An additional set of cages was set out at three to seven of the existing instream stations and was used to measure the relative water velocity through the inner cages at the beginning and end of each 24-hour study. These measurements were taken to determine the effect that sediment buildup on the Nytex™ screen had on water movement through the cages. To accomplish this, the investigators introduced a small pipette with India ink through the neck of the outer bottle and touched the tip of the pipette to the Nytex™ screen at the front of the inner cage. One ml of ink was then allowed to enter the inner cage and the elapsed time to clear the inner cage of ink was measured. Several surface water velocity measurements were taken with an object of near-neutral buoyancy (usually a lemon) in a 10-foot section of stream over the area where the cages were deployed. These were taken at the beginning and end of each 24-hour study and were compared with the clearing rates of the inner cages.

Effluent Sampling and Analyses

Twenty-four hour unchlorinated effluent samples were collected from each facility. ISCO™, 19-liter capacity automatic samplers were used to collect equal-volume aliquots of effluent every 15 minutes. Effluent samples were mixed and separated for toxicity and chemical analyses. The subsample used for toxicity analysis was put on ice and was delivered to the testing laboratory (EPA, Lexington) within six hours of collection. The subsample used for chemical analyses was further divided on site into separate acid-washed glass containers for each series of chemical analyses.

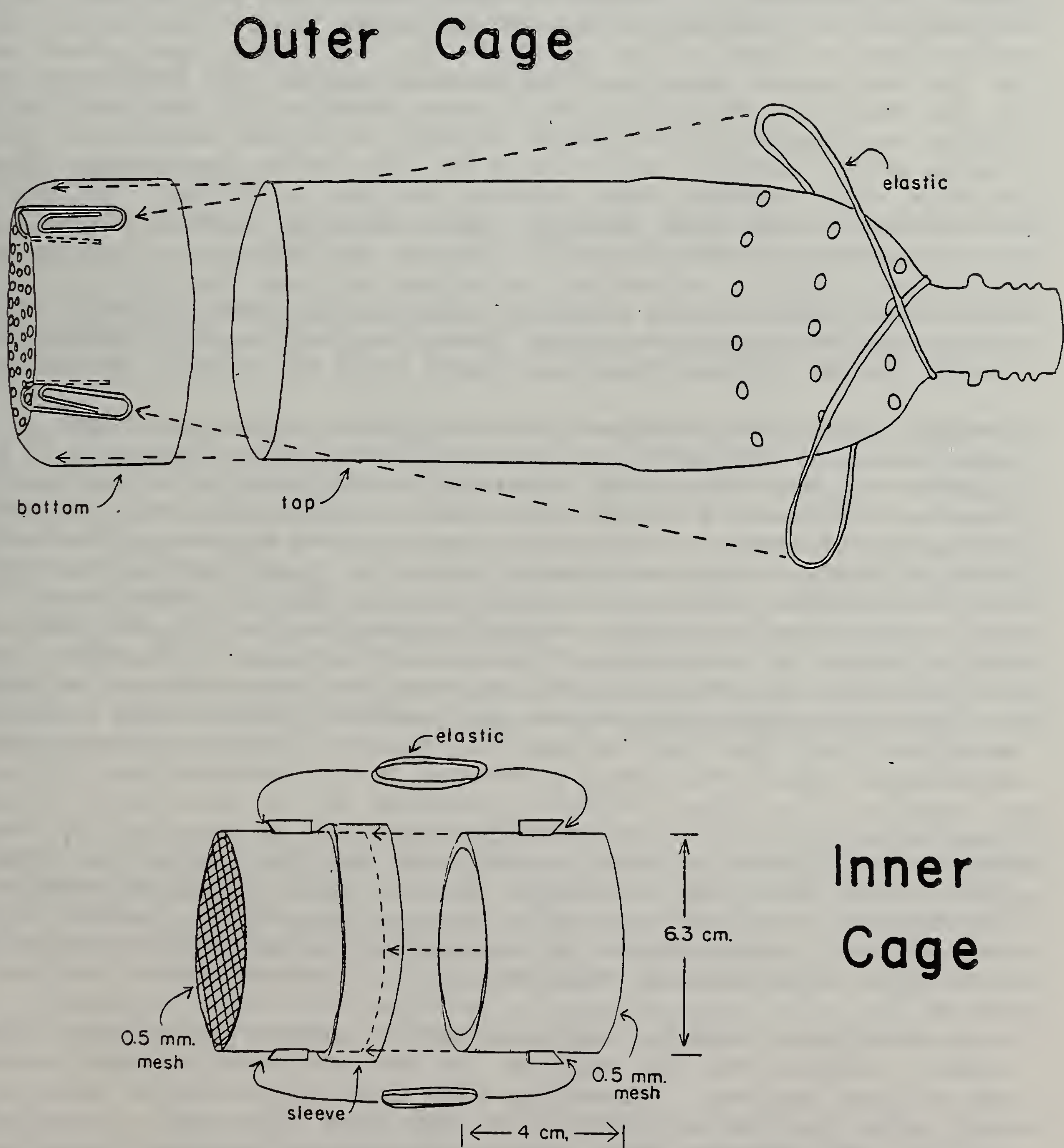
Nutrient and total metals samples were collected in 0.5-liter glass containers and fixed with 2 ml of 50% sulfuric and 50% nitric acid, respectively. Nutrient analyses included total Kjeldahl-nitrogen, ammonia-nitrogen, and total phosphorus. Total metals analyses included the following: silver, aluminum, cadmium, chromium, copper, iron, manganese, nickel, lead and zinc. Approximately 0.5 liters of unfixed sample was filtered through a 0.45 micron filter, fixed with nitric acid and analyzed for "dissolved" metals (the same series as above).

Purgeable organic and acid and base-neutral extractable samples were collected and iced without preservatives. Purgeable organic samples were collected in 60 ml amber bottles with teflon-lined caps. Acid and base-neutral extractable samples were collected in 1.9 liter bottles also fitted with teflon-lined caps. A 1.9-liter sample was collected and analyzed for hardness (Ca and Mg), alkalinity, total and suspended solids and chlorides.

Figure 1. Minnow cage design:

Inner and outer sections of the minnow cages used in the field experiments are depicted. The outer section, which is used to slow the velocity of water passing over the inner cage, is made from an 1-liter, plastic soft drink bottle. Inner cages with minnows are placed inside the top section of the outer cage; the latter is pushed into the bottom section and held in place with elastic bands and paper clips.

Inner cages are constructed from acrylic plastic tube (plexiglass) and Nytex™ screen. The two halves of the inner cage are held together by elastic bands fitted over small plexiglass blocks which are glued to each half of the inner cage. A plexiglass sleeve is placed around the joint of the two halves to prohibit minnows from escaping should one of the elastics fail.



Total organic carbon (TOC) samples were collected in 1-liter plastic containers. All chemical analyses, except for TOC, were conducted by the Lawrence Experiment Station, the Massachusetts Department of Environmental Protection's (DEP) water quality analysis laboratory. TOC analyses were conducted by an EPA contract laboratory. All samples were analyzed according to APHA Standard Methods (APHA, 1985).

Instream Water Quality Analyses

At one-half to three hour intervals over the course of each field study, TRC and a number of water quality parameters were measured at instream stations. Fischer and Porter (series 17T2000) rechargeable amperometric titrators were used at streamside for the field TRC analyses. Wallace and Tiernan (series A-790) amperometric titrators were used for TRC analyses conducted in conjunction with the laboratory toxicity tests.

At the Westborough site, sampling was conducted by one field crew in a canoe. At the other two sites, two field crews travelled to stations via streamside trails: one started at the control station and worked downstream, and the other started at the midpoint test station and also worked downstream. Three to five separate water samples were titrated for TRC at control, effluent and test stations on each of these sampling runs. Chlorine electrodes were cleaned with a chlorine-free cleaner (Bon Ami™) between sampling runs.

The 24-hour water column TRC data sets for each station were compared with minnow survival at that station. These dose-response data sets were evaluated against the EPA fathead minnow mean acute value for chlorine of 105 µg/L TRC.

Precision data were developed for the Fischer and Porter field titrators by experienced technicians in the laboratory using Chlorox™ (5.25% NaOCl) diluted with glass distilled, deionized water (which has a fairly low chlorine demand). A minimum of 30 titrations (5-8 titrations per set) for each of eight TRC concentrations in a geometric series was used to develop the data set. The range in percent relative standard deviation ([100][standard deviation/mean]) for the laboratory data was as follows: for TRC concentrations > 0.1 to 1.2 mg/L, the percent relative standard deviation was 7% or less; this same statistic was 16% or less for TRCs in the 0.04 to 0.1 mg/L range. For TRCs of 0.03 mg/L, the minimum detection limit for this instrument as used in the field studies, the percent relative standard deviation ranged up to 47%. The minimum detection limit for the Wallace and Tiernan titrators when operated by an experienced technician using a micropipet in the laboratory was 0.01 mg/L TRC.

Dissolved oxygen (D.O.), pH and temperature were measured at instream stations when TRC data were collected. The azide modification of the Winkler method (APHA, 1985) was used to monitor D.O. in field-collected samples. Stream temperatures were monitored with precalibrated Taylor (model T2211-4) dial thermometers. Water column pH was measured with a Great Lakes Instruments (model 819) dual buffer pH meter which was calibrated between sampling runs.

Twenty-four hour composite samples of stream water were collected manually from select stations and were analyzed for the same chemical constituents as were the effluent samples. Composites were made by collecting equal aliquots of site water at instream stations during each river run. Grab samples of effluent and instream water were collected for purgeable organic analyses. Instream concentrations of potential toxicants were compared with EPA (1986)

water quality criteria for toxicity to freshwater aquatic life. Criterion levels for metals were calculated using the approximate mean hardness from water samples collected at the test stations. Chlorides were measured in the upstream, effluent and downstream 24-hour composite samples and used to estimate the 24-hr. average IWC of effluents for each of the field studies (see Appendix 1 for the methods used in calculating IWC).

Time-of-travel studies were conducted on the morning of the first instream study at each site. Two methods were used to determine time of travel. At the Westborough site, the stream reach under study was divided into upper and lower segments. Dye was introduced to the head of each segment and the elapsed time of travel of the leading edge of dye (visually determined) to the end of the respective segment was measured. Time of travel to each instream station was calculated by assuming a linear relationship between time of travel and distance in each of the two stream segments. At the Belchertown and Hopedale sites, the stream reach under study was divided into upper and lower segments as at the Westborough site. Dye was introduced to the head of each segment, but time of travel to each station was measured directly.

Laboratory Toxicity Tests

Dilution water used in the laboratory toxicity tests was collected from receiving streams at a point near the control station at each site. Fathead minnows and *D. pulex* were used for testing all effluents. *C. dubia* was used in addition to the other test organisms for three of the five effluents tested. All tests were 48-hour static acute tests. Methods used were those outlined in Peltier and Weber (1985).

Once in the laboratory, effluent samples were mixed, split into equal aliquots, and used in both unchlorinated and chlorine-dosed toxicity tests. Effluent samples used in the unchlorinated tests were run without further treatment. Since the chlorine demand of each effluent was different, the following method was used to estimate chlorine dose: first, each of five flasks containing equal volumes of effluent was dosed with a different quantity of diluted household Chlorox™. Next, these effluent samples were mixed and allowed to sit for 15 minutes to simulate chlorine contact at WWTPs. TRC remaining in each of these flasks was titrated to determine the correct dosage needed to obtain a TRC of approximately 1.0 mg/L. Once the correct ratio of Chlorox to effluent volumes was determined, the remaining effluent was dosed accordingly and used in the chlorinated toxicity test.

The dilution series used in the laboratory toxicity tests (as % effluent) was 100%, 50%, 25%, 10%, and 5%. A control of dilution water only (upstream site water) was also used. For the chlorine-dosed tests, 100% effluent samples containing approximately 1.0 mg/L TRC were diluted to the proper concentrations after which test organisms were immediately added. Next, TRC was measured in each of the test concentrations and the values obtained were used as TRC at time zero of the test. Survival of test organisms was determined after 24 and 48 hours. Dissolved oxygen was monitored at time zero and at 24 and 48 hours after test initiation. As none of the samples dropped below 40% saturation, they were not aerated.

Forty-eight hour survival data were used to estimate the median lethal concentration (LC_{50}) for TRC measured at test initiation. Two methods were

used to calculate the LC_{50}: the graphical method and the Moving Average-Angle method. Percent mortality vs. toxicant concentration is plotted on semi-log paper for graphical estimates of LC_{50}s. This process converts the sigmoid curve of linearly plotted mortality data to a straight line in the vicinity of the LC_{50}, but does not produce confidence intervals for the LC_{50}.

The Moving Average-Angle computer program of Dryer (in Peltier and Weber, 1985) was used to calculate both LC_{50}s and 95% confidence intervals for the acute test data. It was used in place of other methods such as the Probit or Spearman-Karber methods due to the nature of the data sets. Most of the chlorine tests produced either one-hundred percent or zero percent mortality in each test concentration and thus precluded the use of the latter two methods which require partial mortality in a least one or two of the test vessels. The Moving Average-Angle method is a variation of the Probit method which may be used when no partial mortalities occur but is limited to use with data sets in which there are two effluent concentrations above the LC_{50}.

RESULTS

Instream Waste Concentration (IWC)

Chloride concentrations in 24-hr. composite water column samples taken from upstream, effluent and downstream stations differed substantially (see Table 1). This facilitated the calculation of a 24-hr. average IWC, which otherwise would not have been possible without periodic flow gaging throughout the course of each study (see Appendix 1 for methods used in calculating IWC).

TABLE 1
INSTREAM WASTE CONCENTRATION (IWC)

Facility	Date	Upstream [Chloride]	Effluent [Chloride]	Downstream [Chloride]	IWC
Westborough	July 18-19	21	90	80	86%
Westborough	July 19-20	27	120	91.5	69%
Belchertown	Aug. 15-16	80	62	74	33%
Belchertown	Aug. 16-17	89.5	61.5	80	34%
Hopedale	Sept. 13-14	44	60	48	25%

The effluent component (i.e., the IWC) of the total river flow in each of the five field studies averaged 25% or greater. At the Westborough site, the Assabet River becomes a waste dominated stream immediately after the Westborough WWTP input. At the Belchertown site, the IWC over the two field studies was much lower than at the Westborough site and averaged about one-third of the total instream flow. IWC at the Hopedale site was 25 percent of the total stream flow. High IWCs for municipal sewage treatment facilities are not uncommon in Massachusetts. Of approximately 100 WWTP discharges to freshwater systems, about 35 have an IWC of 20 percent or greater at periods of low flow (7Q10 conditions instream).

Field Studies: Effluent Impacts to Caged Minnows

In each of the five field studies conducted, minnow survival was adversely impacted at stations located downstream of WWTP outfalls (see Figures 2.1 to 2.3 and Appendix 2). Wastewater chlorination was judged to be the cause of these impacts for two reasons: first, minnow survival at control stations in the field studies was acceptable (85% or greater in all five studies) and did not reveal any adverse effects from upstream sources. Second, none of the unchlorinated effluent samples collected in conjunction with the field studies was found to be toxic when evaluated through toxicity tests conducted in the laboratory (see Laboratory Toxicity Tests). In addition, mixtures of unchlorinated effluents with receiving water samples were also found to be non-toxic in these tests. As a result of these findings, field impacts at test stations were considered to be due to the toxic effects of chlorine addition to wastewaters.

The downstream extent of effluent impacts on caged minnow survival varied considerably from site to site. In the two Westborough evaluations, substantial impacts to minnow survival were seen only at the test station closest to the discharge (the 21 m station). Minnow survival at this station was 15 and 20%, respectively, on the first and second field studies. At the next closest test station to the discharge (the 247 m station) minnow survival was 80% at the end of the first study and 100% at the end of the second study. As a result, the downstream limit of the zone of 24-hr. acute toxicity to minnows in these studies lay somewhere between 21 and 247 m downstream from the confluence of the effluent with the Assabet River. Water column travel time to the 247 m station (the "recovery station") was approximately 18 minutes (see Figure 3.1 and Appendix 3). Minnows held at other stations farther downstream from the 247 m station also appeared to be unaffected by the effluent. Low survival at the control station (85%) and at test stations (80%), other than the 21 m station on the first Westborough study was probably related to handling.

In both of the studies conducted at the Belchertown site, minnows suffered 100 percent mortality throughout a 122 m zone downstream of the WWTP outfall. Minnow survival was higher at stations located downstream of the 122 m point (the 183 and 244 m stations) but was only 40 to 50% of the survival observed at the control station. Habitat constraints prohibited the placement of minnows downstream of the 244 m station. Water column travel time to the first test station where minnow survival exceeded zero percent (the 183 m station) was approximately 23 minutes (see Figure 3.2 and Appendix 3.2).

Reduced minnow survival extended throughout the 518 m test area at the Hopedale site. The zone of 100% mortality at this site, however, extended only to the 61 m station. Minnow survival downstream of the 61 m station increased steadily to a high of 80% at the 518 m station. Travel time of the water column to the 518 m point was over two hours (see Figure 3.3 and Appendix 3.3).

Field Studies: Evaluations of Minnow Cage Design

The clearing time of ink introduced into most cages at 24-hours was not severely reduced from that at time zero (see Appendix 2) although partial

Figures 2.1 to 2.3. Minnow survival in field studies at select instream stations. Distance to downstream stations was measured from the point of effluent discharge to the receiving stream.

FIG. 2.1 Westborough Site

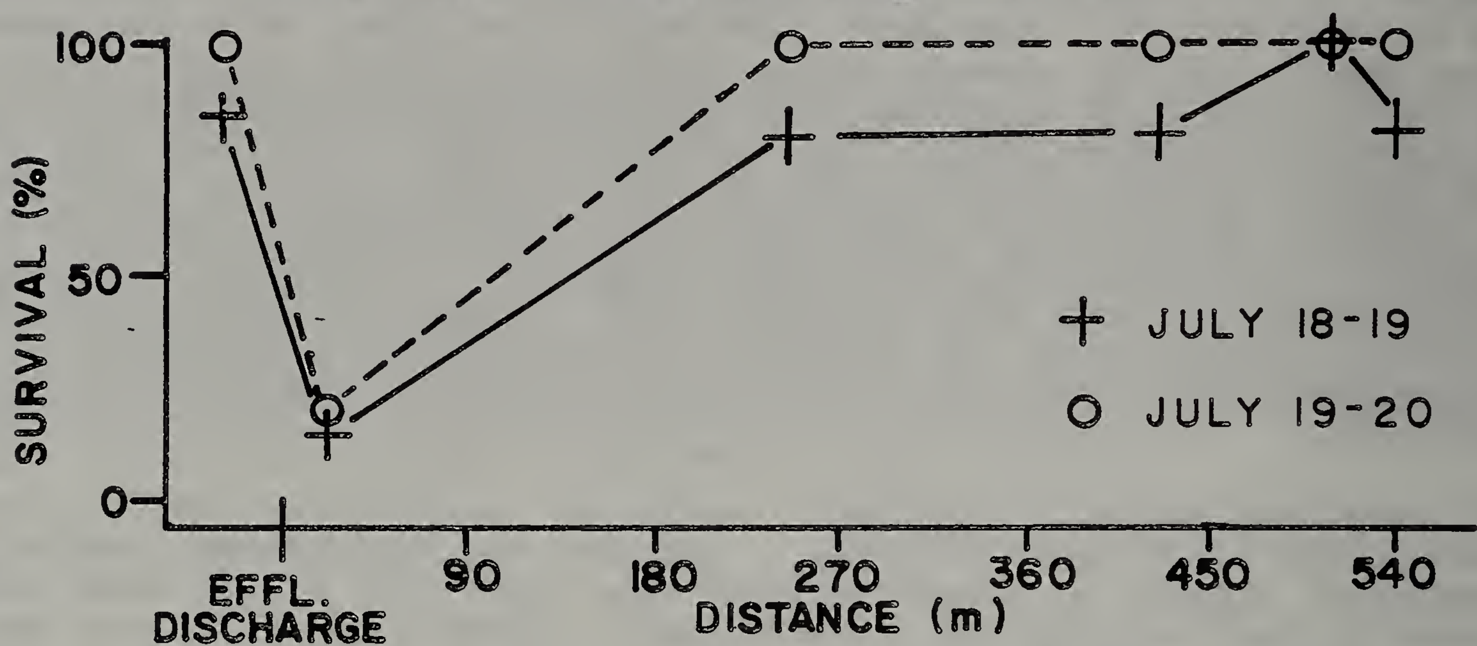


FIG. 2.2 Belchertown Site

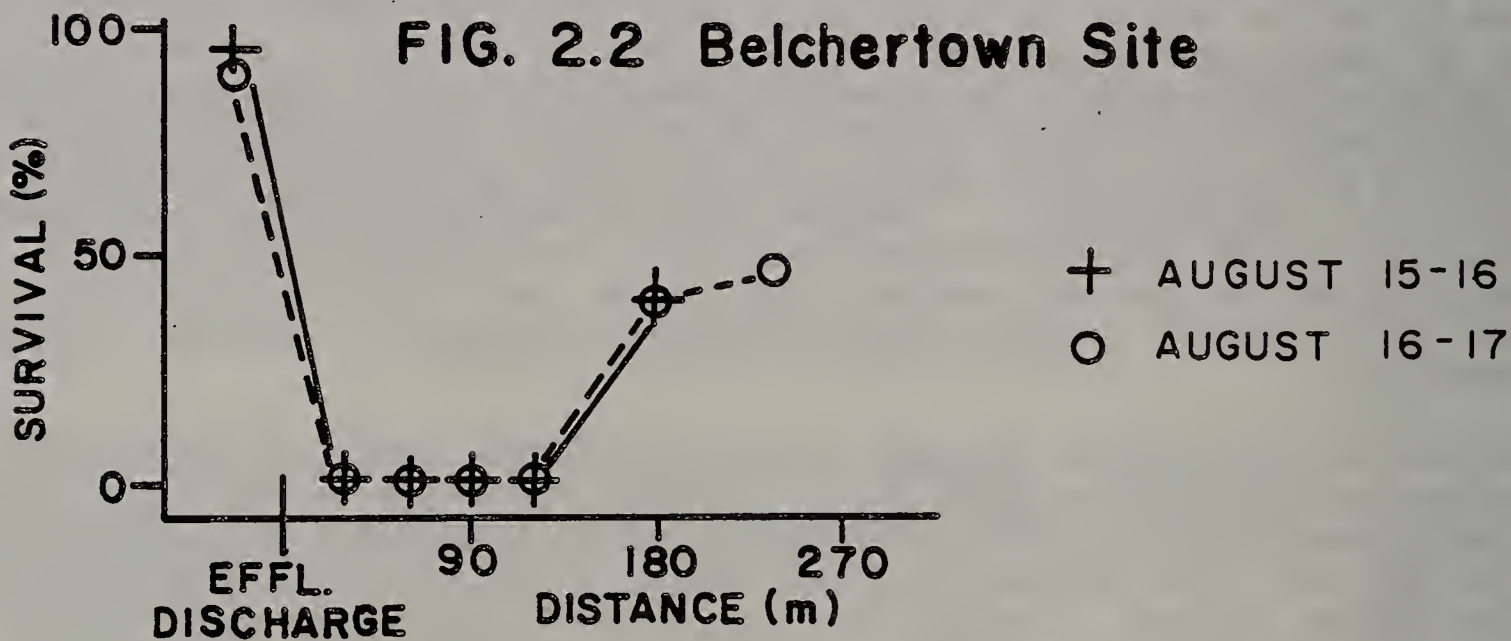
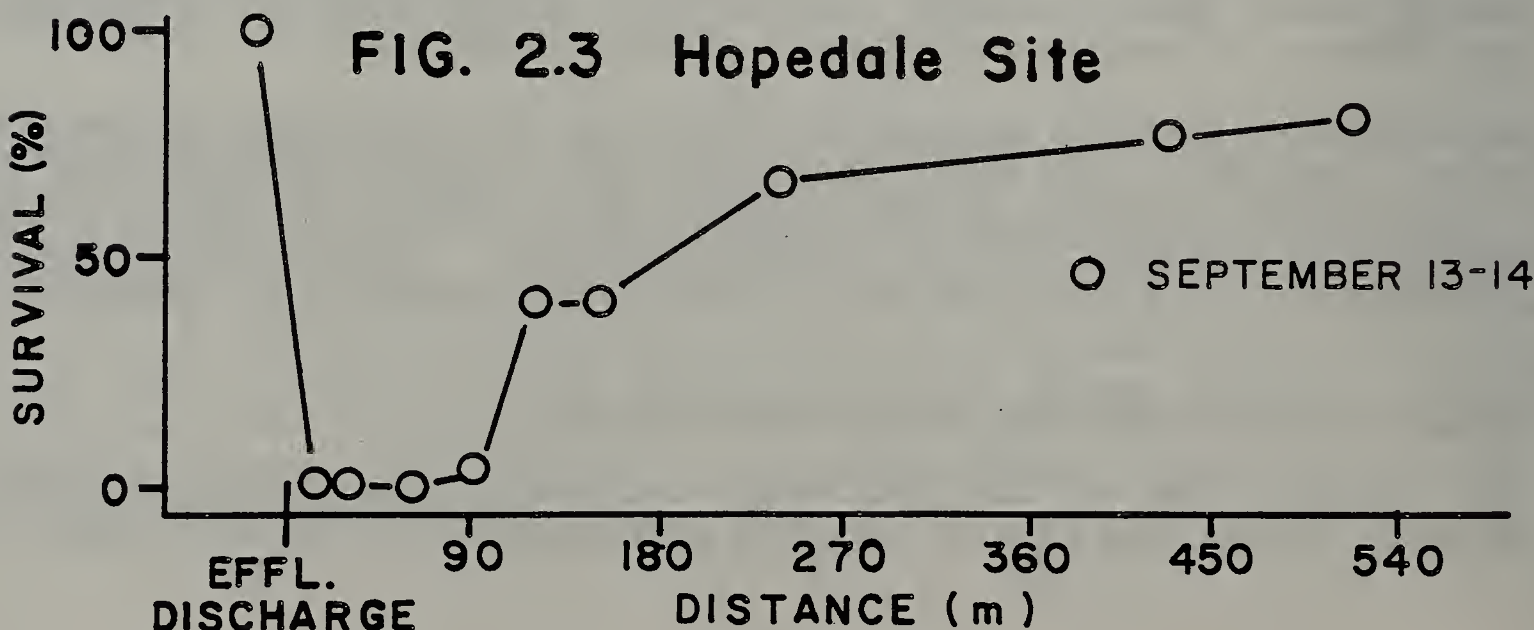


FIG. 2.3 Hopedale Site



Figures 3.1 to 3.3. Minnow survival in field studies vs time-of-travel from WWTP outfalls. Time-of-travel data taken from dye studies (see Appendix 3).

FIG. 3.1 Westborough Site

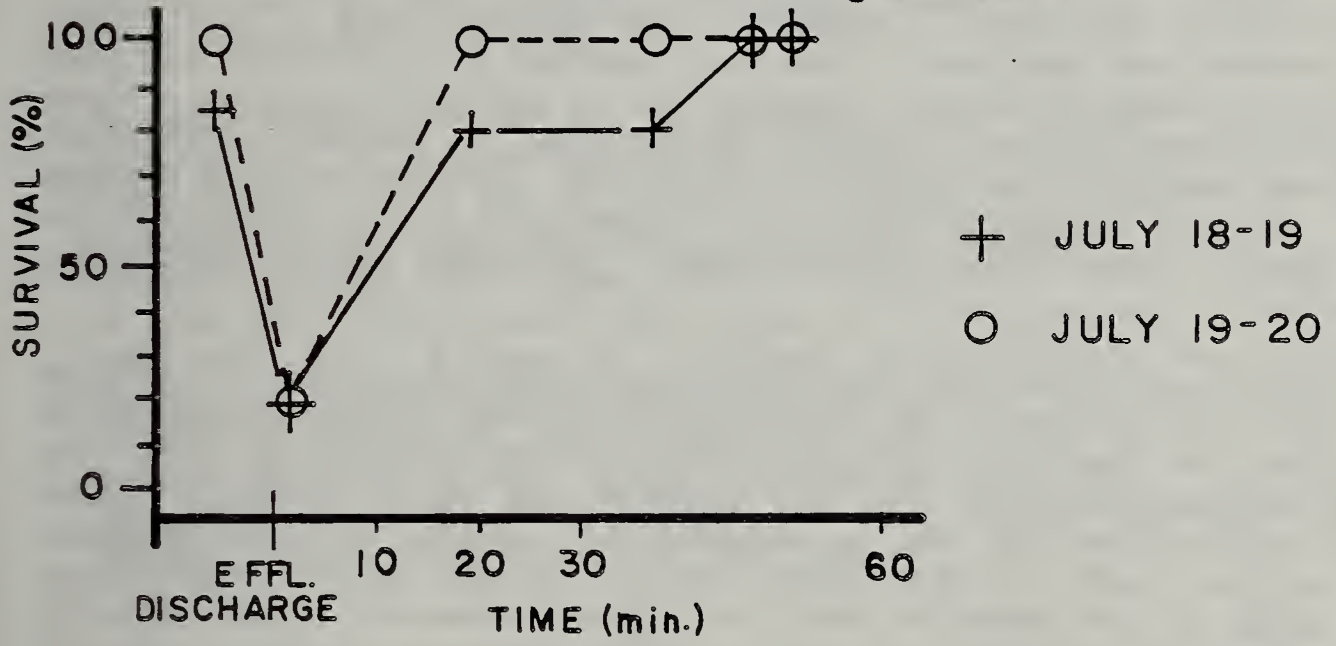


FIG. 3.2 Belchertown Site

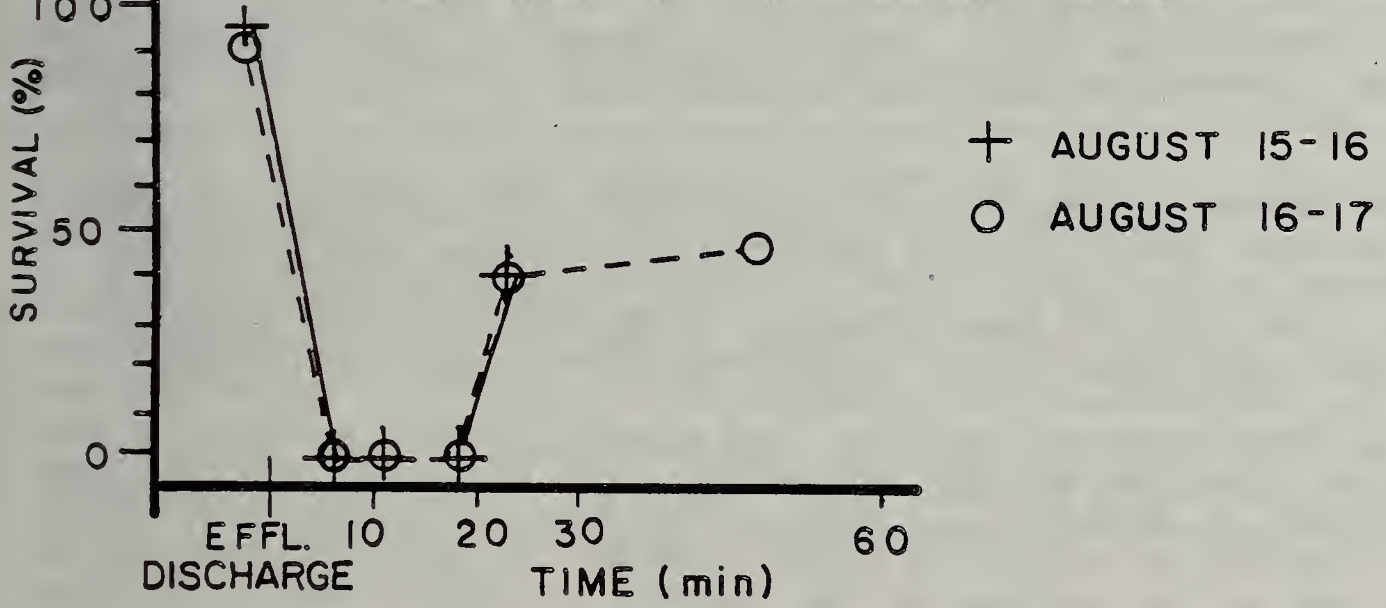
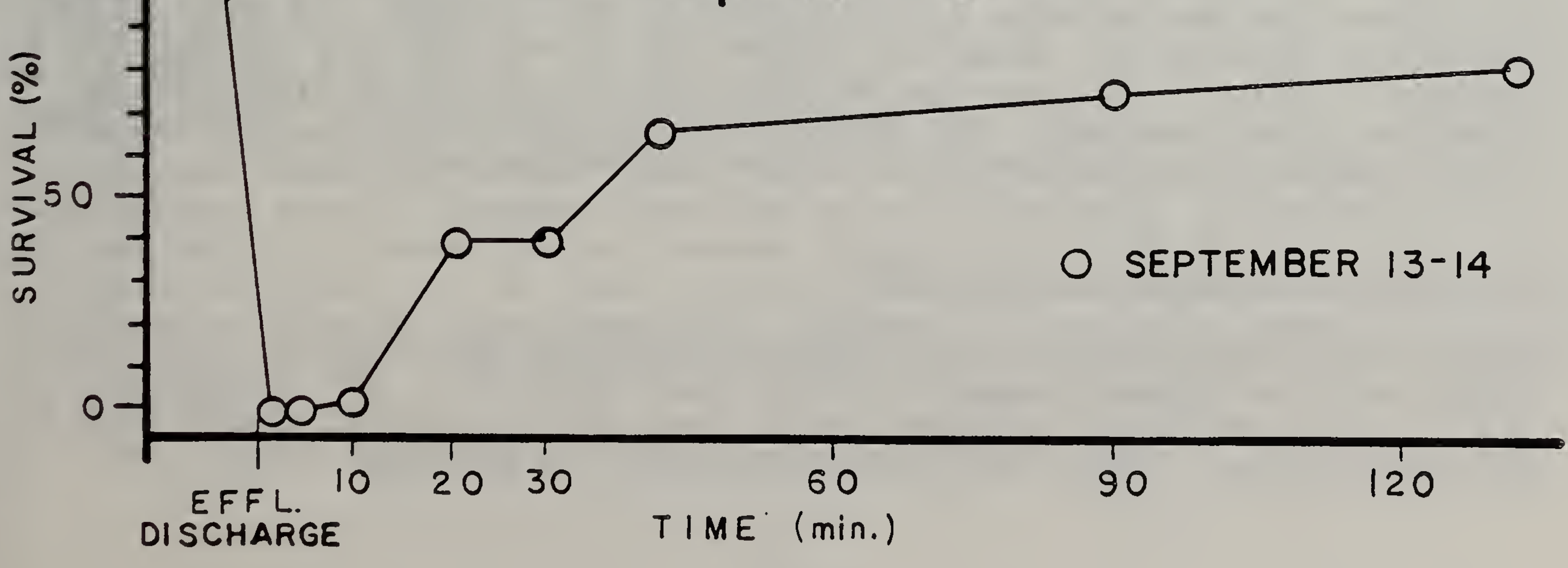


FIG. 3.3 Hopedale Site



occlusion of screen surfaces was observed after 24 hours in each of the studies. Clearing time at most stations in these studies was less than three minutes. Although the length of time to clear each cage of ink was expected to be negatively correlated with stream velocity, this was not always the case.

In each of the studies, the Nytex™ screen on the upstream face of the minnow cage was often covered with sediment. Cages at instream stations that had very low water velocities seemed to be most susceptible to sediment build-up. Field crews expressed the opinion that instream evaluations in excess of 24-hours might result in near-complete occlusion of the screens with sediment at certain stations. The authors recommend that if studies are to be conducted for periods longer than 24 hours with this equipment, the cages should be removed and cleaned daily.

High water velocities may have had an effect on minnow survival in studies conducted at the Belchertown site, but probably not in the studies conducted at the other two sites. On the first study conducted at the Westborough site, the highest velocity measurement (0.18 m/s) was taken at the 424 m station. Minnow survival at this station was 80% and is comparable to minnow survival observed at the control station (85%) on this first study. In the second Westborough study, minnows caged at the station with the highest measured water velocity (0.27 m/s) exhibited 100 percent survival. Thus, water velocities did not appear to affect minnow survival at the Westborough site.

Instream velocities at the Hopedale site were all below the maximum velocities seen at the Westborough site. Mechanical stress to caged minnows from excessive water velocity was, therefore, probably not a factor in the survival of minnows at this site.

The velocity-mortality data from the Belchertown site are not as easily interpreted as these same data from the other two sites. In each of the two studies conducted at this site, water velocity measurements taken at four of the stations in the complete kill zone (0 - 122 m) exceeded the highest levels observed at the Westborough site. In addition, water velocities at these four stations at the Belchertown site exceeded those measured at other instream stations where minnow survival was high. As a result, minnow survival at four of the instream stations at the Belchertown site may have been at least partially affected by mechanical stress. This does not affect the overall evaluation of impacts as much as it might, however: stream velocities at the 91 m station (one of the stations in the complete kill zone) were at or below those measured at the Westborough site where minnow survival was 100 percent. As a result, minnow mortality between the effluent and the 91 m station at the Belchertown site was probably due to effects of the effluent. In order to rule out the possibility of mechanical stress on minnow survival at the 122 m station at this site, separate studies would have to be conducted at a toxic-free site to establish the upper limits of stream velocity in which cages of this design can be deployed without affecting minnow survival.

Field Studies: Effects of Temperature

Stream temperatures alone did not appear to affect minnow survival in the field studies as water column temperatures were all below 32° C (see Appendices 4.1 to 4.3), the approximate incipient lethal level for the fathead minnows used in the field studies. (Hart [1947] established that the incipient lethal level

for fathead minnow fry cultured at 20° C, the same temperature at which minnows used in these studies were cultured, was 31.7° C.) Water temperatures at the control station at the Westborough site ranged from 23 to 27° C over the course of the two instream studies. Stream temperatures downstream of the effluent discharge at this site ranged from 22 to 25° C over the course of study.

Stream temperatures at the Belchertown site covered a fairly wide range due to a cold snap on the second day of the study. Temperatures at this site ranged from 16 to 23° C at the control station and from 19 to 26° C at the test stations during the two days of field studies. Effluent temperatures were slightly higher than those found at the control site. This may have been due to the fact that the effluent pipe at the Belchertown site drained the top of the last in a series of treatment lagoons which were relatively unshaded. Higher temperatures at downstream stations may have contributed to water column oxygen depletion at this site (see below) due to the inverse relationship between temperature and oxygen saturation in water. Instream temperatures at the Hopedale site were fairly low and varied very little between control (14-20° C) and test (14-19° C) stations.

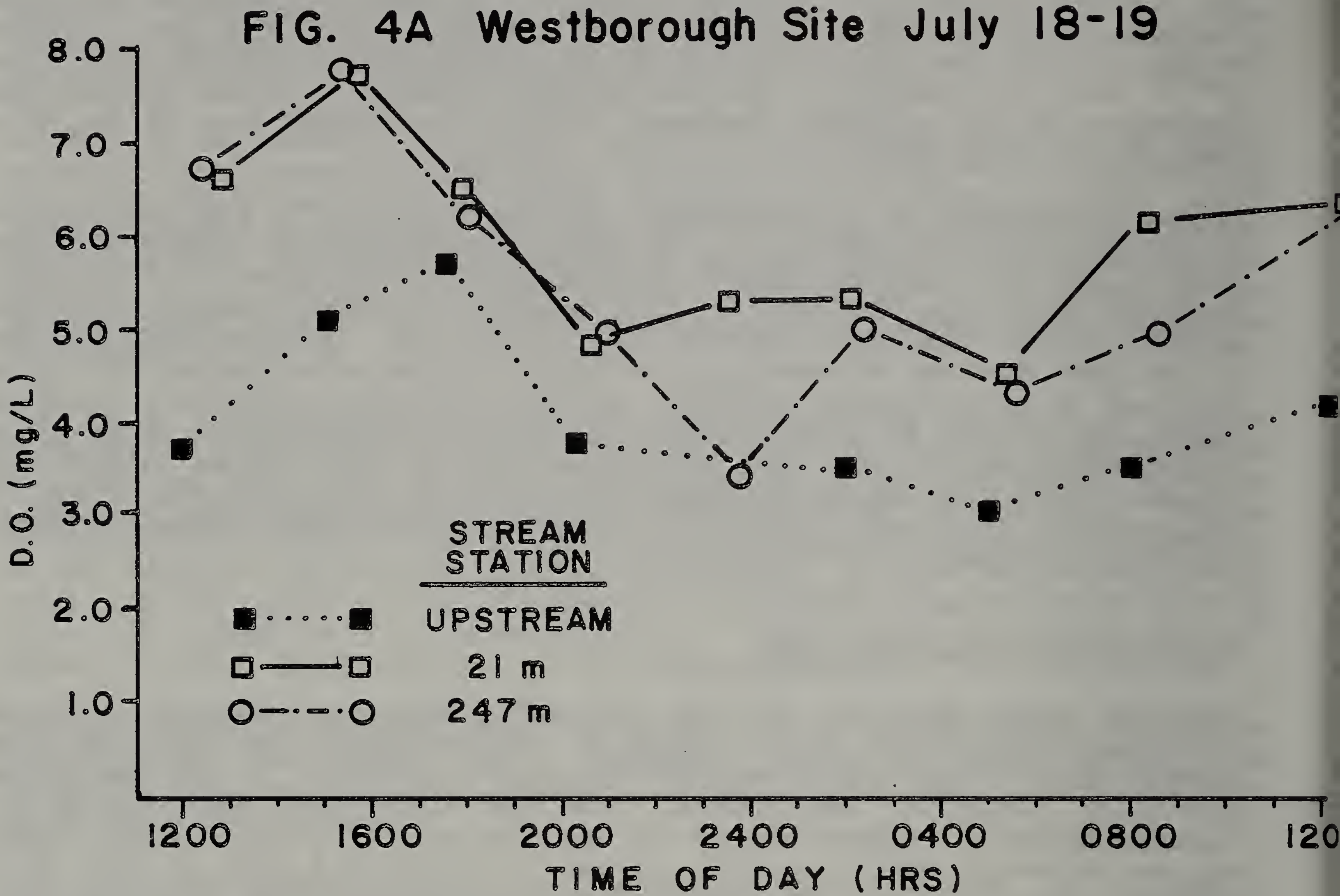
Field Studies: Dissolved Oxygen

Dissolved oxygen data for the five instream studies are presented in Figures 4A-4E (and Appendix 4). D.O. levels at the Westborough and Hopedale sites probably did not have an adverse effect on minnow survival. At the Westborough site, D.O. levels at test stations were much higher than they were at the control station and remained above 4.0 mg/L throughout the two studies, except on one occasion, where the D.O. reached a low of 3.8 mg/L at the 247 m station. D.O. levels at the control station at this site fell below that to a low of 2.9 mg/L during the first 24-hr study. Minnow survival at the control station was acceptable (85 and 100% on the first and second studies, respectively). As a result, oxygen concentrations alone should not have affected minnow survival at test stations at the Westborough site.

Dissolved oxygen concentrations at the Hopedale site were fairly high throughout the study. The lowest level recorded at any station was 4.5 mg/L at the 91 m station. At these concentrations, D.O. probably did not adversely affect minnow survival.

Water column D.O. concentrations at the test stations at the Belchertown site were low, about half what they were at the control station at any point in time. Lowest levels of D.O. were measured at the last two test stations, the 183 and 244 m stations. In addition to the oxygen demand from the Belchertown WWTP effluent, shading, substantially lower stream velocities and benthic oxygen demand probably acted to diminish D.O. levels at the 183 and 244 m stations where the stream flowed into a wetland (see Site Descriptions). At the test station farthest from the point of effluent discharge (the 244 m station) D.O. concentrations reached a low of 1.7 mg/L at approximately 2200 hours on August 16. At this low level of D.O., minnow survival may have been directly affected (see Discussion) although it should be noted that minnow survival at the 244 m station was slightly (5%) higher than that at the 183 m station.

Figures 4A to 4E. Dissolved oxygen (D.O.) concentrations at select instream stations.



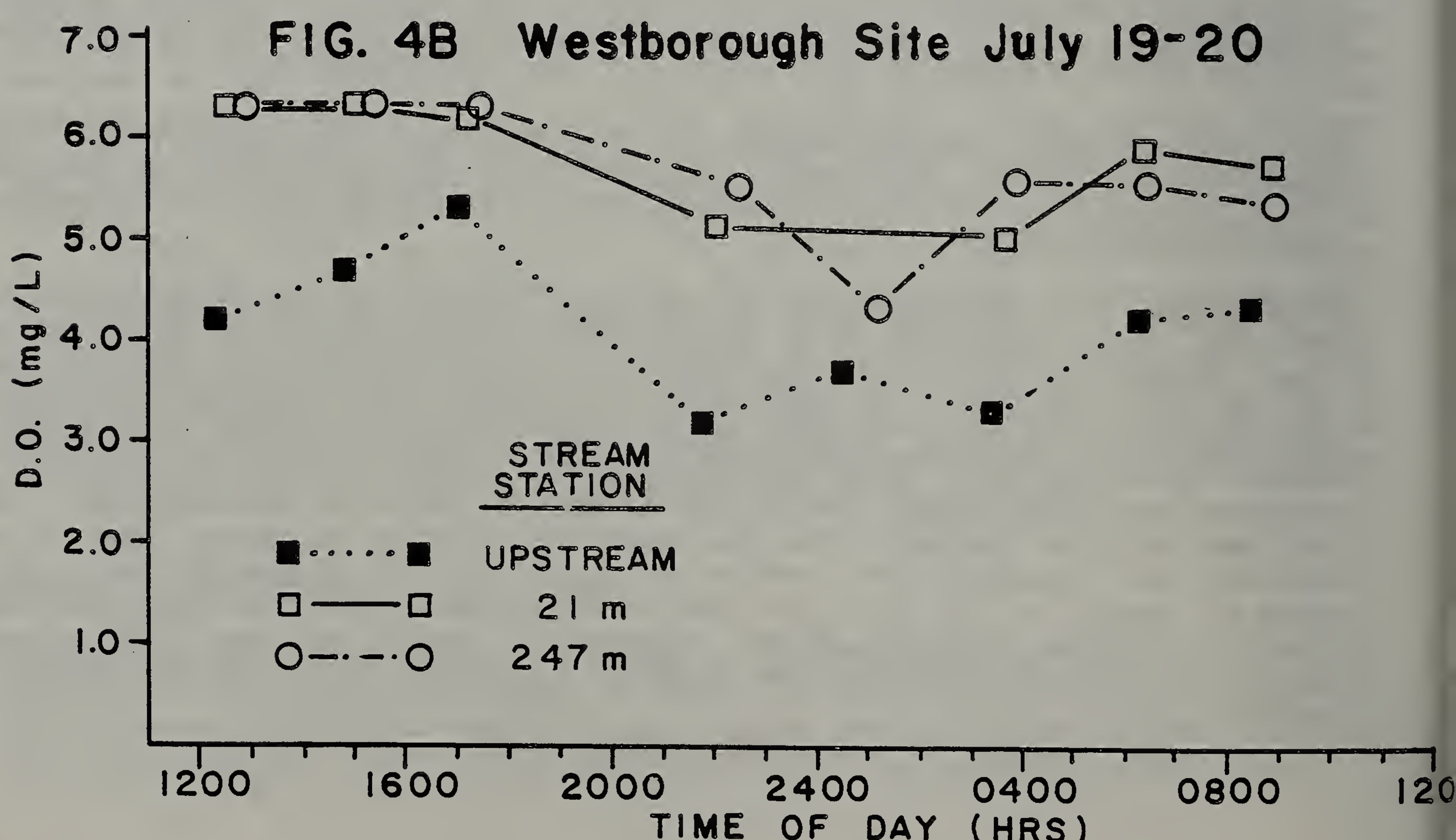


FIG. 4C Belchertown Site Aug. 15-16

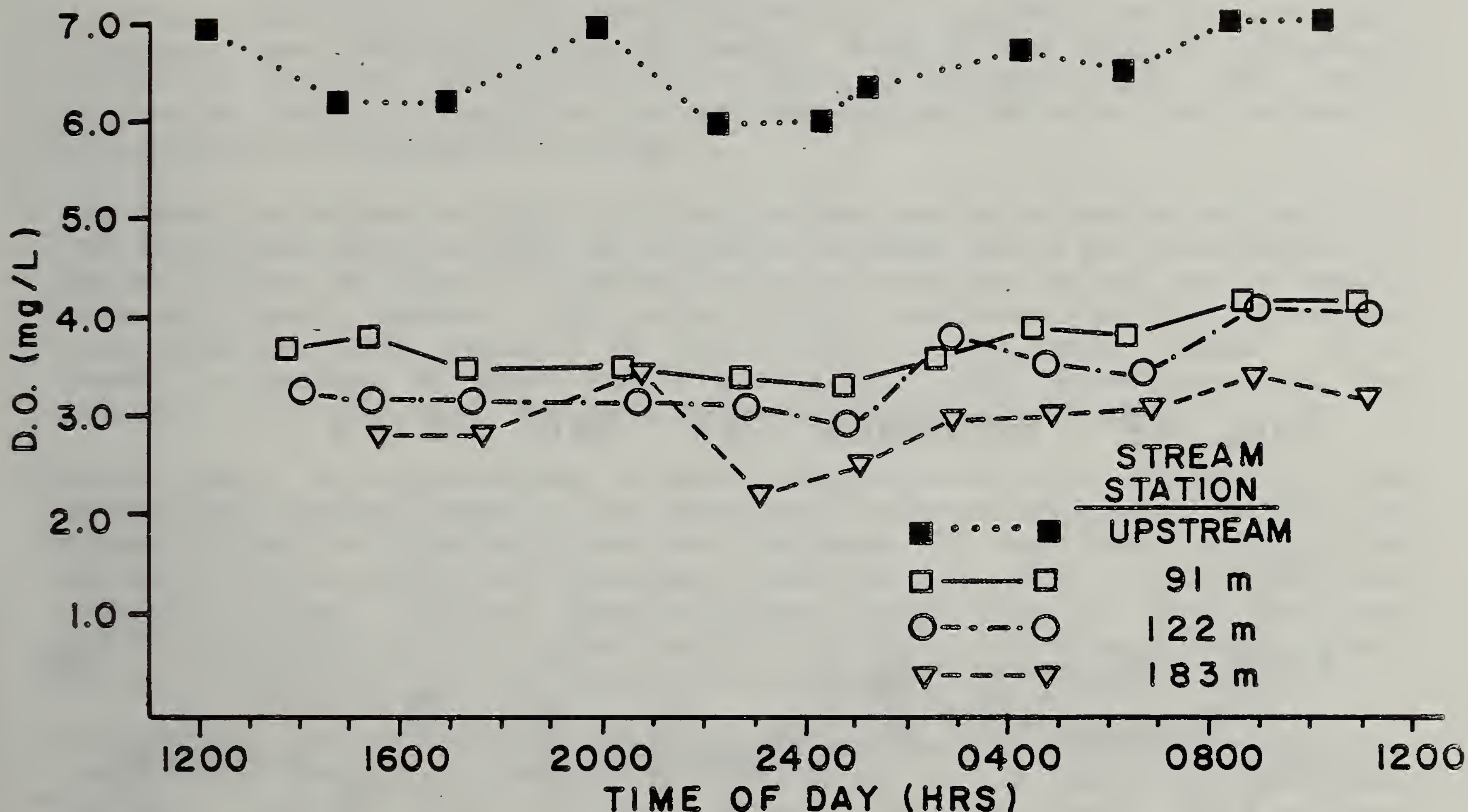


FIG. 4D Belchertown Site Aug. 16-17

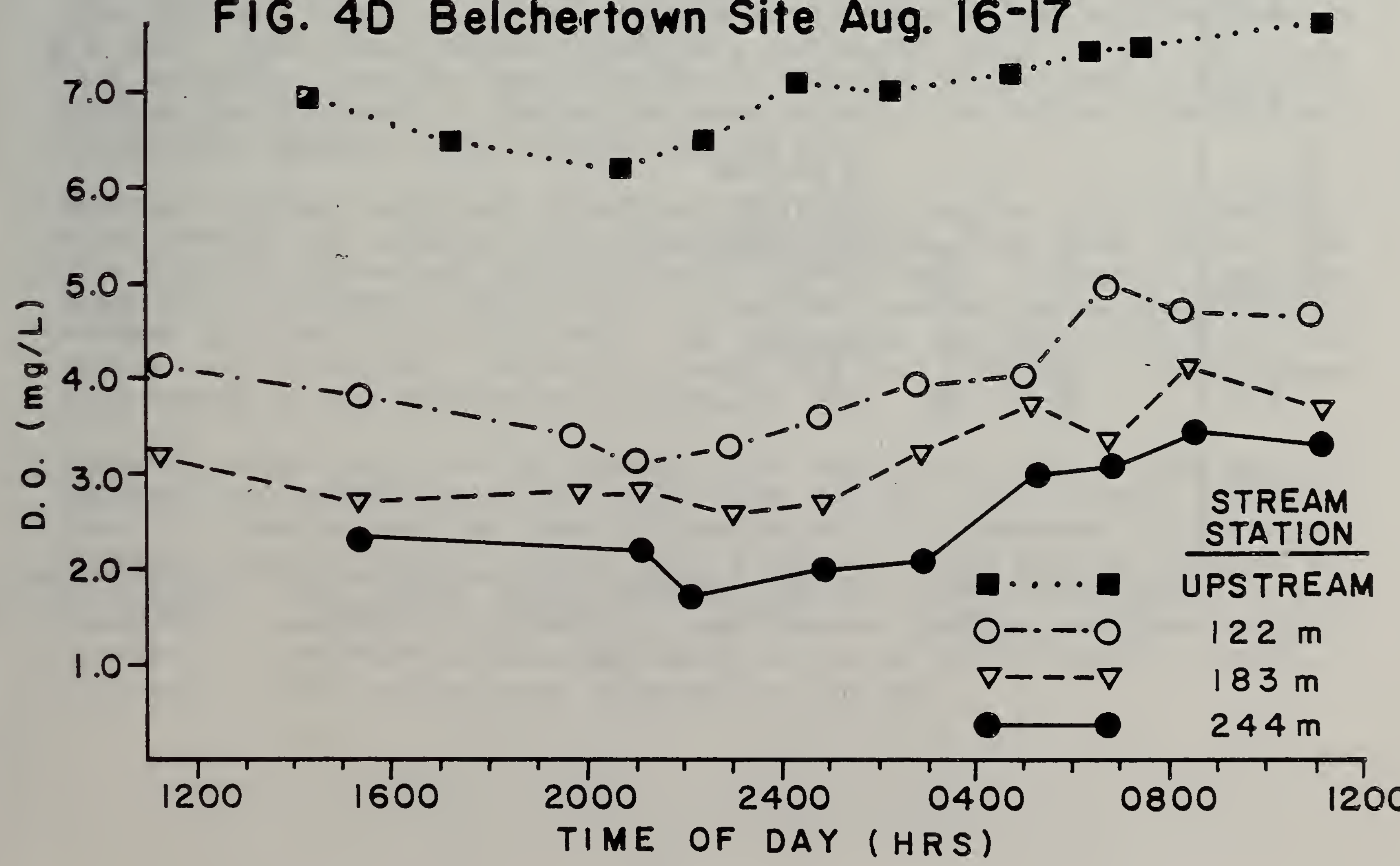
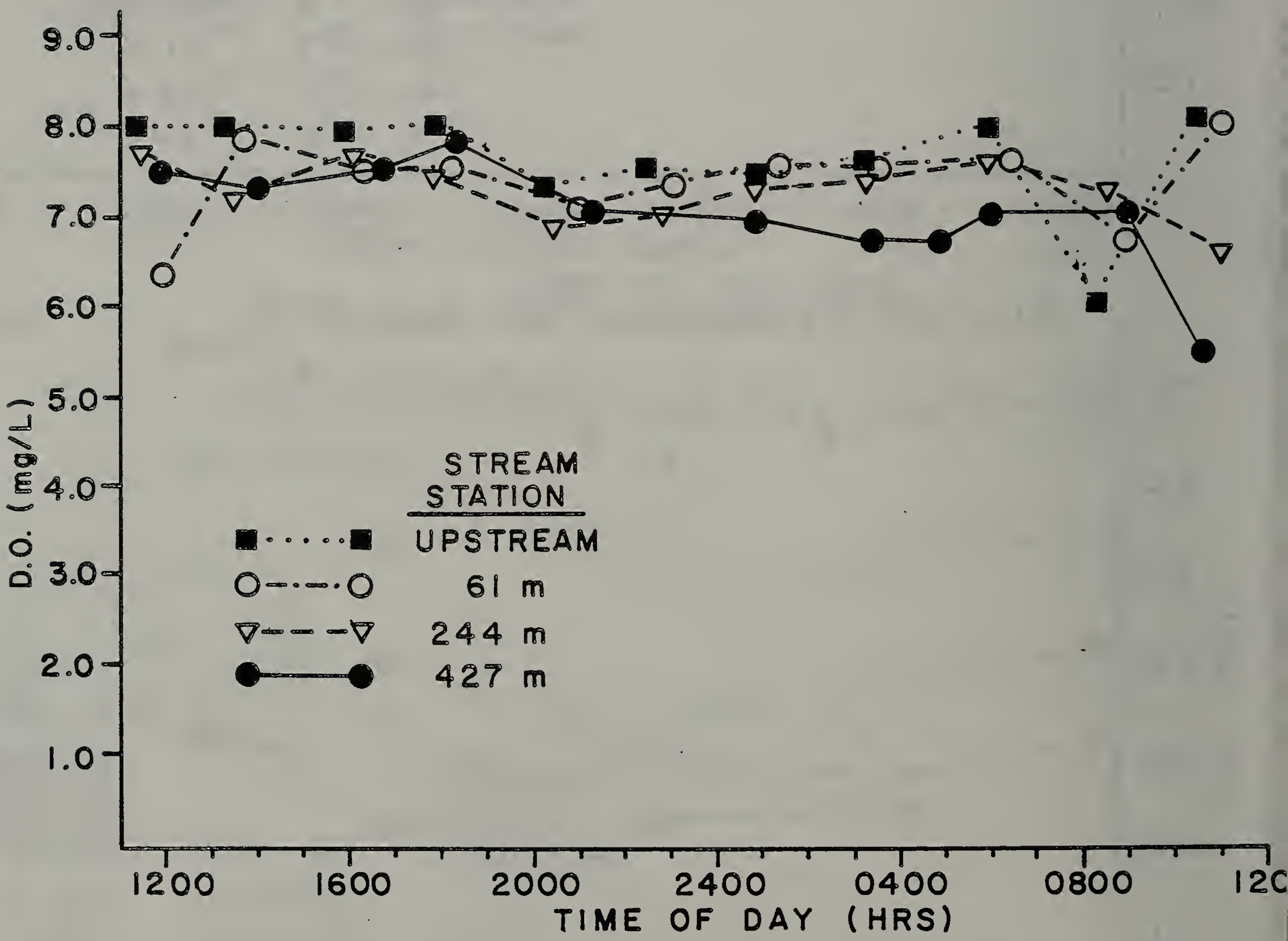


FIG. 4E Hopedale Site Sept. 13-14



Field Studies: Chemical Analysis of Water and Wastewater

Although none of the unchlorinated effluent samples was toxic to the laboratory organisms (see Laboratory Toxicity Tests), some of the chemical parameters evaluated exceeded EPA acute water quality criteria (EPA, 1986) by a substantial margin. Results of the chemical analysis of water and wastewater are presented in Appendices 5 through 9.

The levels of copper and zinc from the instream composite samples collected at the Westborough site exceeded the EPA acute criteria levels for those metals by up to a factor of five. Dissolved levels of these two metals, on the whole, were much lower, however. The latter finding indicates that the two metals were probably being complexed by particulates in the water column. As a result, a portion of these metals was probably not bioavailable and the potential toxic effects of the total metals were thereby reduced.

Large peaks of butoxyethoxy ethanol acetate were also detected in the Westborough effluent sample in the extractable organics analysis. Although no quantification of this substance was performed it was found only in the effluent samples and probably dissipated substantially prior to mixing with the receiving stream. Instream ammonia-nitrogen levels were low (most were less than 0.5 mg/L) and did not exceed the EPA (1984b) 4-day average criterion level of 1.2 mg/L for the range of temperature and pH levels measured at this site.

Total copper and zinc concentrations at the Belchertown site exceeded the EPA (1986) acute criteria levels but dissolved levels of the same metals were much reduced. Instream ammonia-nitrogen exceeded the EPA (1984b) 4-day average criterion level of 1.1 mg/L for the range of temperature and pH measured at this site by a factor of 1.6 to 3 at each of the instream test stations on both surveys. While these ammonia levels were not acutely toxic to the laboratory test organisms, they may have altered the toxicity of chlorine in the field studies (see Discussion). Neither purgeable organics nor acid and base neutral extractables appeared to be a problem at this site.

Chemical analyses conducted on effluent and water samples from the Hopedale site revealed the presence of benzene (unquantified) that moved through the site but this contaminant was not found in the effluent. Tolerance of aquatic organisms to benzene is quite high. The EPA freshwater acute criterion for benzene is 5,300 $\mu g/L$ (EPA, 1986). As minnows at the control site did not suffer any mortality, benzene probably did not adversely affect minnow survivorship in test stations at this site.

Ammonia-nitrogen levels at the Hopedale site ranged from 0.06 to 0.08 mg/L at instream test stations and were well below the EPA 4-day average criterion level for ammonia over the range of temperature and pH measured at this site. Purgeable organics did not appear to be a problem in the samples collected at this site. Total copper values exceeded the EPA (1986) acute criterion but dissolved values for this metal did not. Levels of dissolved iron slightly exceeded the EPA chronic criterion level in one of the instream composites; analyses for total iron were not conducted at this site.

Field Studies: Effluent TRC Levels

Effluent TRC levels (see Figures 5.1 to 5.3 and Appendix 10) in the Westborough-Shrewsbury WWTP effluent were fairly stable over the course of the two field studies conducted at that site and ranged between 0.35 and 0.7 mg/L. At the Belchertown site, effluent TRC levels were much less stable. Measured TRC concentrations in the Belchertown WWTP effluent ranged from 0.33 to 2.9 mg/L. Although the effluent TRC concentrations measured at the Hopedale WWTP were between 0.35 and 1.4 mg/L, actual effluent levels probably exceeded the 1.4 mg/L value, as high concentrations of TRC were observed at some of the test stations at one point in the study (see Field Studies: TRC vs. Minnow Mortality).

Field Studies: TRC Dissipation

Total organic carbon (TOC) content of water column samples was positively correlated with the disappearance rate of TRC. TOC data are available for only the studies conducted at the Westborough and Belchertown sites (see Appendices 5A-5D). TOC in the water column samples collected at instream test stations at the Westborough site ranged from 15 to 17 mg/L. The water column travel time to the 536 m station at the Westborough site measured approximately 50 minutes. Maximum recorded TRC levels in the effluent and 536 m station measured at the Westborough site were 0.7 and 0.2 mg/L, respectively. In addition, TRC levels at the 536 m station exceeded the limits of detection for most of the period of measurement over the two days of study.

TOC concentrations in composite samples collected from test stations at the Belchertown site were about 50% higher than those at the Westborough site, and ranged from 21 to 24 mg/L for the two days of study. TRC levels in the effluent at the Belchertown site during the second day of study when the 244 m station was in use, ranged from 0.33 to 2.9 mg/L. TRC concentrations measured at the 244 m station during this time did not reach detectable levels. TRC concentrations measured at the 183 m station at this site were below detection throughout the two days of study, but reached 0.095 mg/L at one point during the second day of study. Water column travel time from the effluent discharge to the 183 and 244 m stations was approximately 23 and 50 minutes, respectively. Judging from these data, the extinction rate of TRC at the Belchertown site was much higher than that at the Westborough site and was correlated with higher levels of TOC.

TRC values measured at the test station farthest from the effluent discharge at the Hopedale site ranged up to 0.1 mg/L. Water column travel time to this station was over two hours. Although the highest effluent concentration measured at this site was 1.4 mg/L, actual effluent concentrations probably exceeded this value.

Field Studies: TRC vs. Minnow Mortality

Figures 6A to 6E depict diel TRC measurements taken over the course of each 24-hr. study field study at select instream stations at each site. TRC data for the other instream stations may be found in Appendix 10. Station selection for these figures was based on minnow survival data from each of the studies. At the Westborough and Belchertown sites, there were dramatic changes in minnow

Figures 5.1 to 5.3. Total residual chlorine (TRC) levels (mean of 3 to 5 readings) in effluents. TRC readings taken over the course of two consecutive 24-hr. studies at the Westborough and Belchertown sites, and one 24-hr. study at the Hopedale site.

FIG. 5.1 WESTBOROUGH POTW

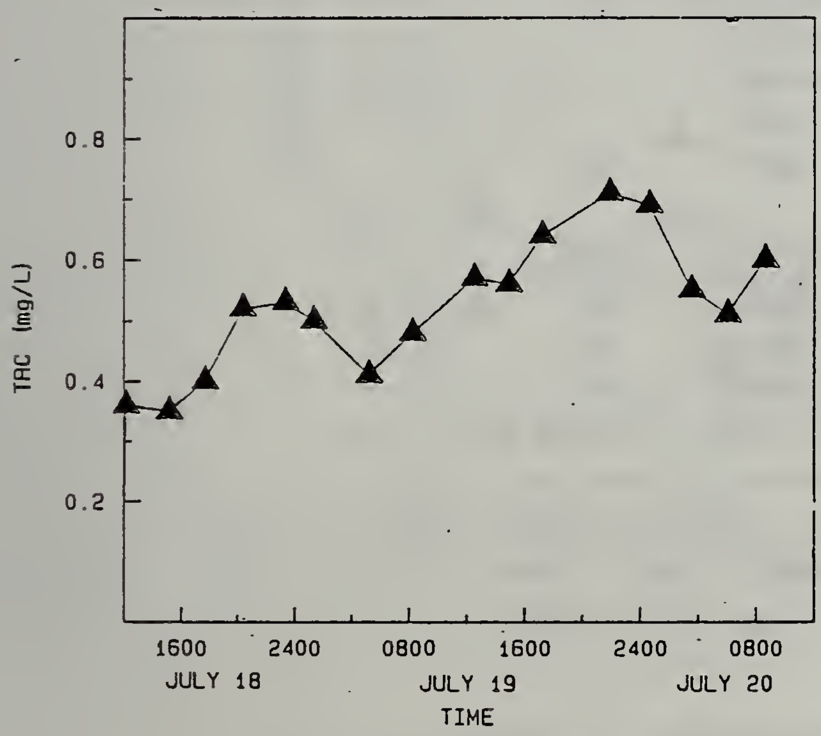


FIG. 5.2 BELCHERTOWN POTW

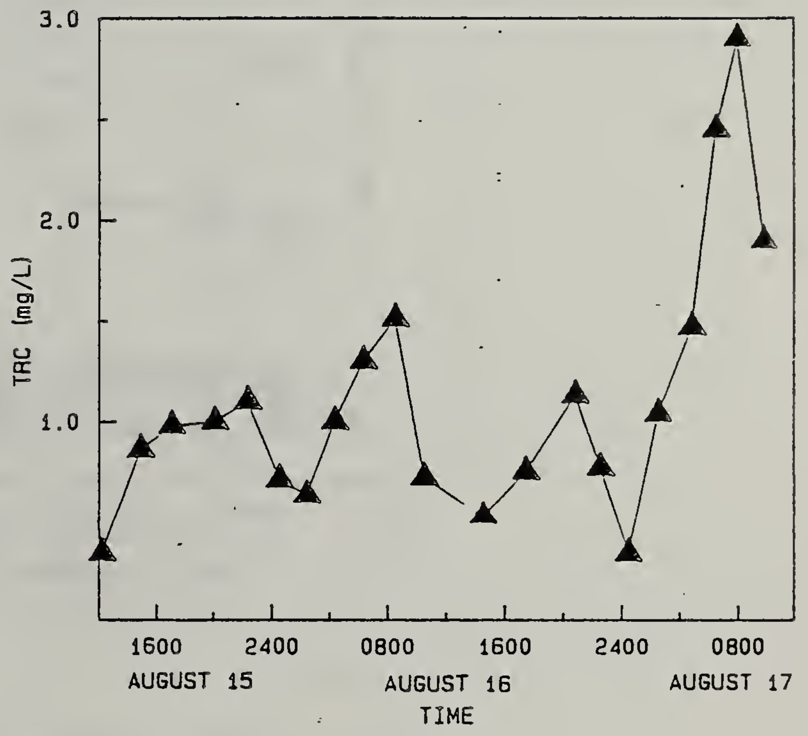
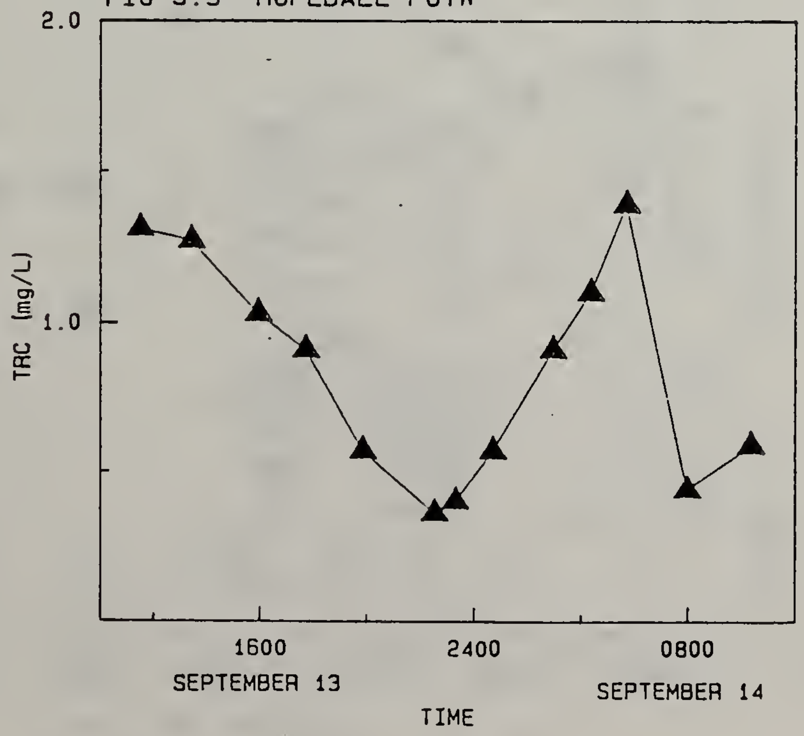
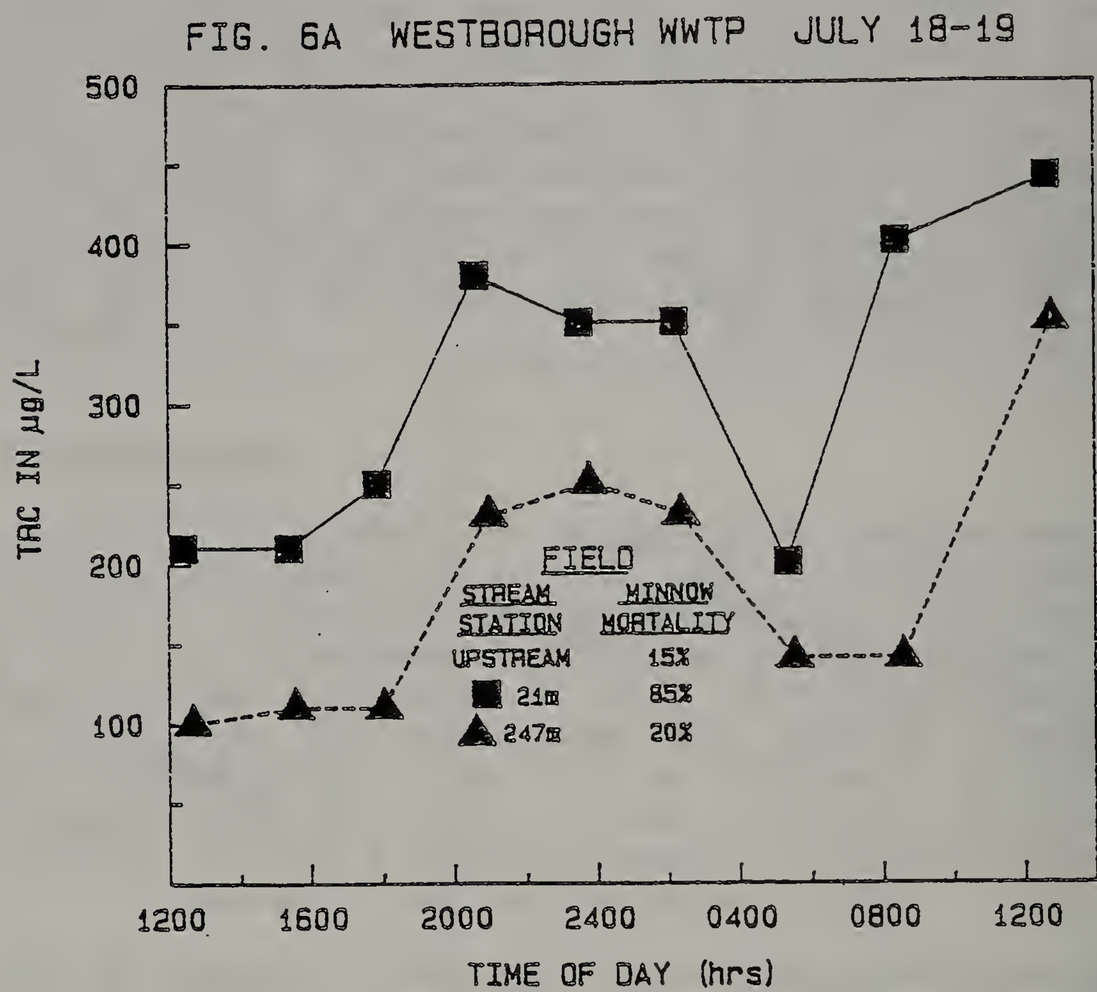


FIG 5.3 HOPEDALE POTW



Figures 6A to 6E. Mean total residual chlorine (TRC) concentrations recorded at select instream stations over the course of five, 24-hr studies. Field mortality data for caged fathead minnows are also provided.



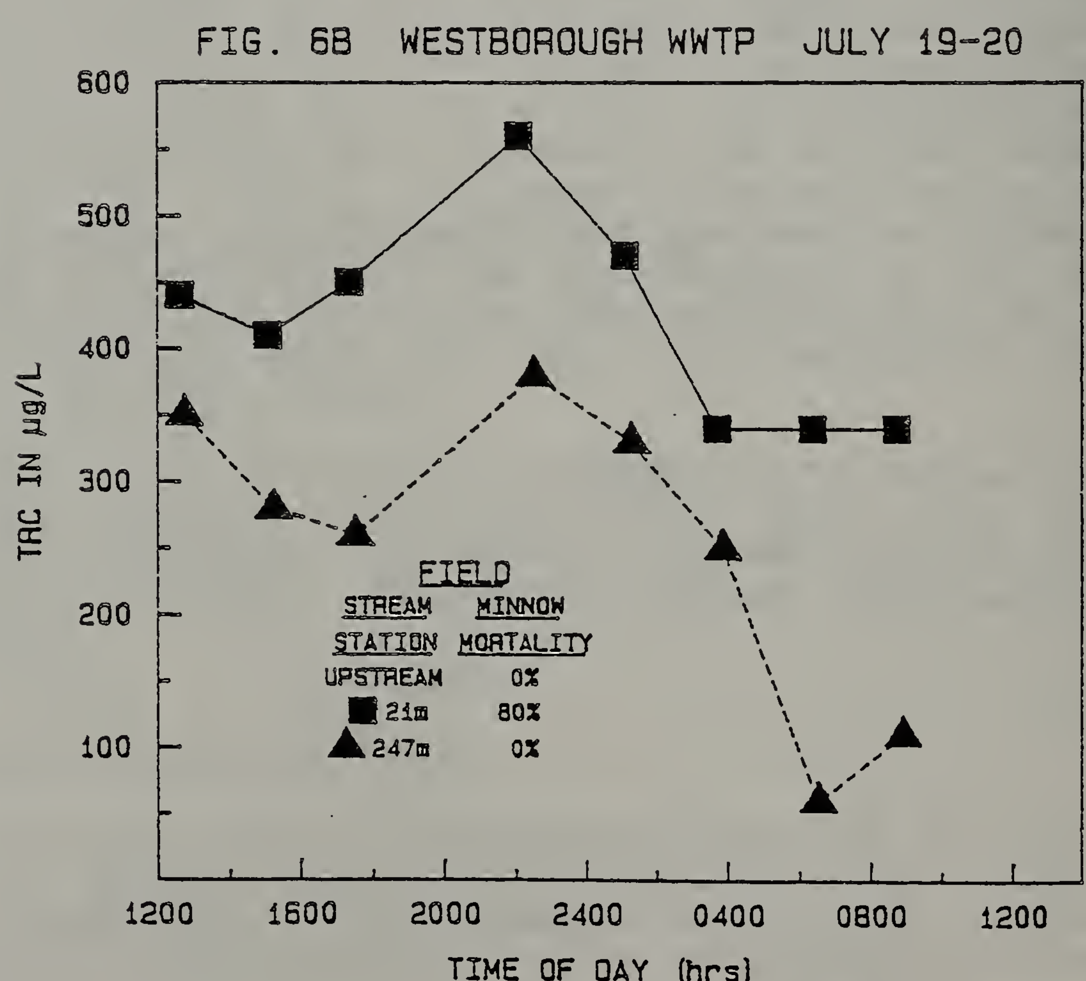


FIG. 6C BELCHERTOWN WWTP AUGUST 15-16

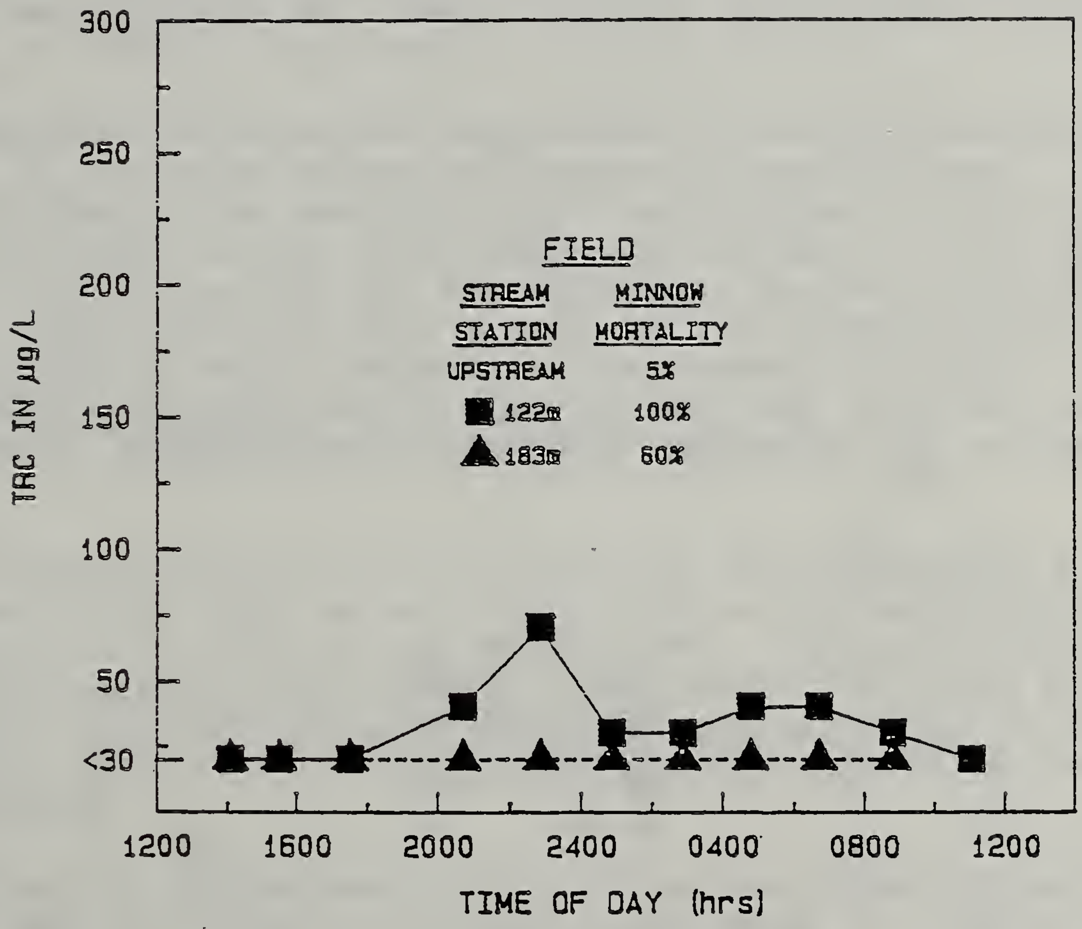


FIG. 6D BELCHERTOWN WWTP AUGUST 16-17

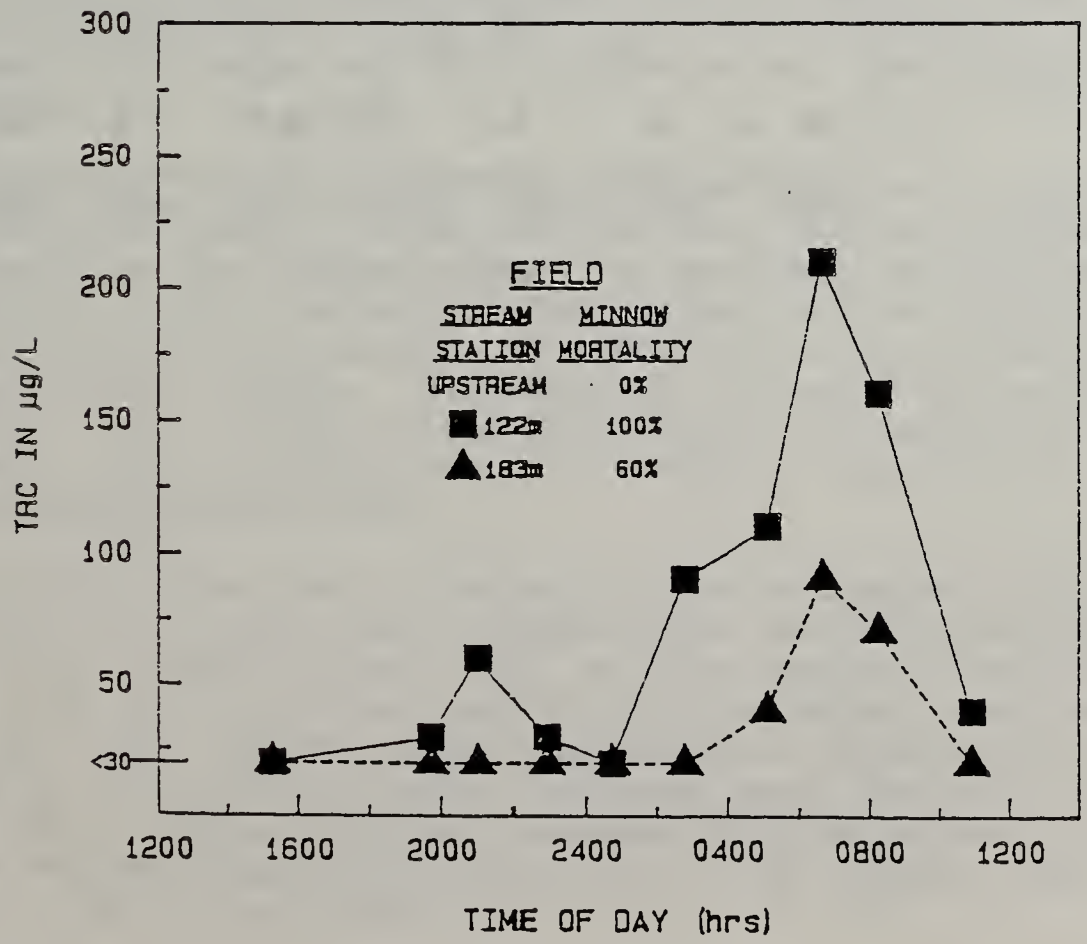
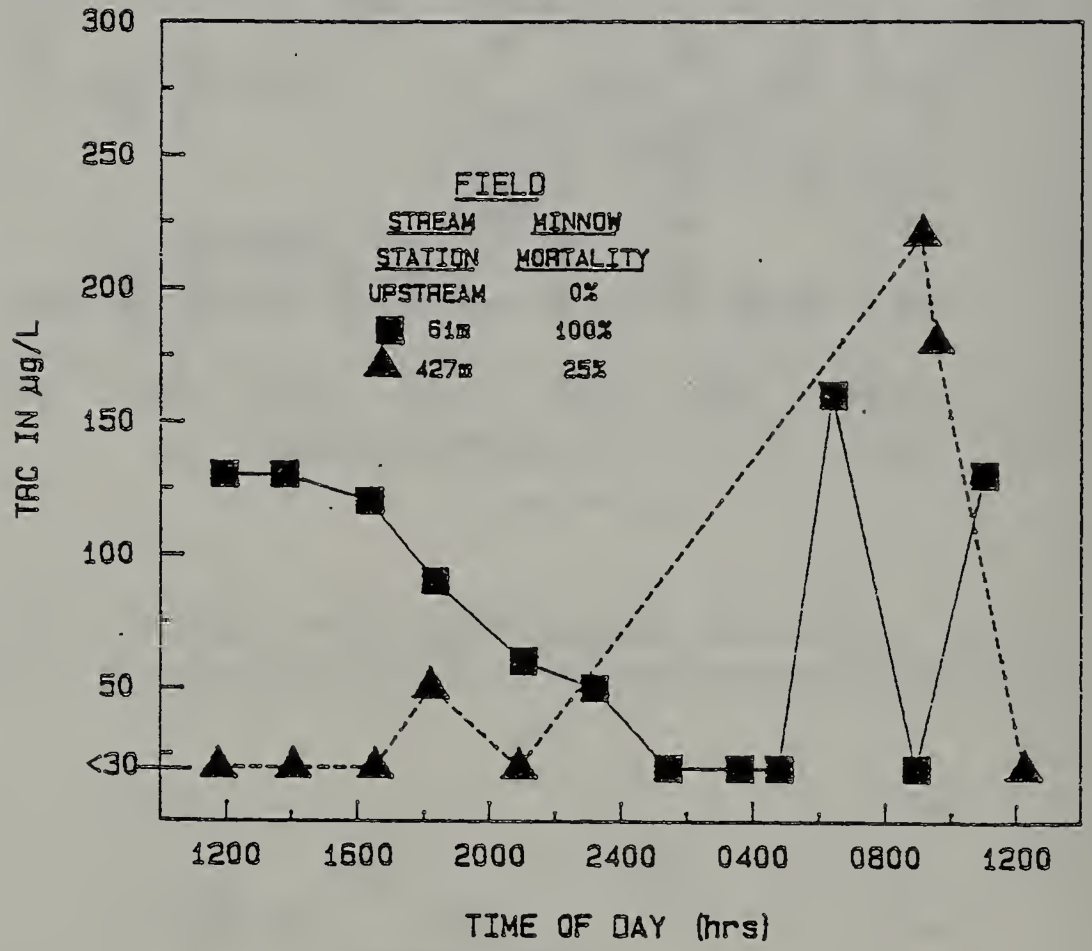


FIG. 6E HOPEDALE WWTP SEPTEMBER 13-14



survival between certain contiguous stations; TRC data from these stations are presented in the figures. At the Hopedale site, the differences in minnow survival between stations was more gradual. For the latter site, TRC concentrations at the most downstream station where 100% minnow mortality was observed are compared with TRC levels measured at the test station farthest from the point of effluent discharge.

There were substantial differences among sites in the relationship between TRC concentrations in the water column and impacts to caged minnows. Minnows held at the 247 m station at the Westborough site were exposed to TRC concentrations that reached 350 µg/L on the first study and 380 µg/L on the second study. Although these levels exceeded the EPA fathead minnow mean acute value of 105 µg/L TRC (EPA, 1984a) for more than 21 hours on the first study and 16 hours on the second, survival of test organisms was not severely affected. On the first study, caged minnow survival at this station was 80%, only 5% lower than the control survival. Minnow survival at this station on the second study was 100%.

A few hardy minnows held at the 21 m station at the Westborough site survived very high doses of TRC. TRC concentrations at this station reached 450 µg/L on the first study and 560 µg/L on the second study. TRC concentrations at this station exceeded the EPA (1984a) fathead minnow mean acute value by at least 90 µg/L for the full 24 hours of each study. Although mortality to caged fish at this station was high, 15% of the minnows survived the first study and 20% survived the second.

Minnows caged at the Belchertown test stations succumbed at much lower TRC concentrations than did those at the Westborough site. On both of the studies conducted at the Belchertown site, minnow mortality was 100% at instream test stations as far downstream as the 122 m station. The highest TRC recorded at the latter station in the first study was only 70 µg/L. During the second study, TRC levels at this station exceeded the 105 µg/L fathead minnow mean acute value for approximately three hours and reached 220 µg/L at one point during the study, but minnows held at this station may have succumbed at a much lower level of TRC.

Caged minnow survival at the Belchertown site was observed at only the 183 m station on the first study. This was the test station farthest from the effluent discharge on the latter study. An additional station was installed downstream at 244 m for the second field study (minnow survival was also observed at this station; see below). Survival at the 183 m station was 40% at the conclusion of both studies. Measured TRC concentrations at this station were less than 30 µg/L throughout the first study but reached 95 µg/L during the second study. The 95 µg/L level is essentially the same as the species mean acute value established by EPA.

TRC concentrations at the 244 m station at the Belchertown site were below detectable levels (0.03 mg/L TRC) throughout the second field study. Minnow survival was only slightly higher (5%) at this station than at the 183 m station. As noted in a previous section of this report (see Field Studies: Dissolved Oxygen) water column oxygen concentrations reached fairly low levels (2.2 to 4.1 mg/L) at the 183 m station, and even lower levels (1.7 to 3.4 mg/L) at the 244 m station. Minnows already stressed from the effects of low D.O. at these stations may have been more susceptible to TRC toxicity than they would have been if D.O. levels were higher.

Chlorine levels during the first 12 hours of the study conducted at the Hopedale site steadily declined and reached non-detectable levels at all stations downstream of the 122 m station by 0200 hours. TRC levels remained low until about 0600 hours when a surge of TRC was observed at some of the test stations that were farthest from the effluent discharge. The highest values recorded for this chlorine slug were at the 244 m station where measured instream TRC concentrations reached 280 µg/L. TRC values at this station and other stations closer to the discharge probably exceeded this level but were not caught soon enough to be measured. Timing of the sampling run did not coincide with this particular chlorine surge and this precluded tracking the TRC pulse at all stations. Since this TRC excursion was not well characterized, comparisons of minnow survival to TRC levels measured instream would provide only a very conservative estimate of minnow exposure to TRC at this site. From a regulator's viewpoint, perhaps the most important bit of information gained from the field study at this site was the fact that chlorine-related acute impacts to minnows were documented over 500 m, two-hours travel time, downstream of the Hopedale WWTP discharge.

Laboratory Toxicity Tests

None of the unchlorinated effluent samples was toxic to the test organisms. Test organism survival in unchlorinated effluents and mixtures of these effluents with diluent (upstream site water) was 90% or greater. Survival of test organisms in dilution water controls was also 90% or greater.

The range in LC_{50} values from one study to the next at any one site was quite large (see Table 2). For example, the LC_{50}s for the chlorine-dosed tests conducted on the Westborough effluent were 168 and 78 µg/L TRC for minnows and D. pulex, respectively, for the first study at that site. LC_{50}s for these two test species were approximately 100% greater for the second study (327 and 150 µg/L TRC, respectively, for minnows and D. pulex). Differences in results for the two samples analyzed at the Belchertown site were almost as great for all three test species.

LC_{50}s for the chlorine-dosed tests with minnows were all in excess of the EPA fathead minnow mean acute value of 105 µg/L. In addition, all five LC_{50}s for chlorine-dosed effluents using fathead minnows exceeded LC_{50}s from the flow-through tests reported in the chlorine criterion document from which the mean acute value was calculated. LC_{50}s for the flow-through tests ranged from 82 to 130 µg/L. These results are not surprising since the chlorine-dosed tests were run in static mode with TRC concentrations that decreased constantly throughout the course of testing.

The confidence limits for many of the chlorine-dosed LC_{50}s are fairly wide. Part of the variability observed may be due to the differential reactivity of chlorine in aqueous solutions, especially at low concentrations (Nolan, 1988). This can result in measured TRC concentrations that are greatly different from those predicted based on dilution alone. As a result, intermediate TRC concentrations which may have caused partial mortalities were not included in the dilution series. For most of the acute tests, LC_{50}s were thereby calculated based on all or nothing responses over a broad dilution range. Confidence limits for this type of data set are often quite broad.

TABLE 2

1988 CHLORINE TOXICITY STUDY

SUMMARY OF

LABORATORY TOXICITY DATA*1

SITE*2	DATE	SPECIES*3	LC_{50}*4 ($\mu g/L$)	95% C.L.*5	NOAEL*6	LC_{50}*7 ($\mu g/L$)
Westborough WWTP	7/19	1	168	114-317	60	180
Westborough WWTP	7/19	2	78	63-100	10	60
Westborough WWTP	7/20	1	327	267-410	230	470
Westborough WWTP	7/20	2	150	102-231	15	133
Belchertown WWTP	8/16	1	274	230-318	30	295
Belchertown WWTP	8/16	2	65	34-118	30	80
Belchertown WWTP	8/16	3	40	28-58	20	40
Belchertown WWTP	8/17	1	196	145-267	110	195
Belchertown WWTP	8/17	2	34	30-38	ND	35
Belchertown WWTP	8/17	3	22	18-27	ND	24
Hopedale WWTP	9/14	1	231	162-424	90	240
Hopedale WWTP	9/14	2	73	67-77	20	72
Hopedale WWTP	9/14	3	24	18-30	10	27

*1: Results from chlorine-dosed whole effluent 48-hr. static acute toxicity tests
*2: Effluents collected from each site as a 24-hr. composite prior to chlorination, subsamples composted every 0.25 hrs.
*3: 1 = Pimephales promelas; 2 = Daphnia pulex; 3 = Ceriodaphnia dubia
*4: LC_{50} using Moving Average Angle techniquie. Results expressed as concentration of total residual chlorine (TRC) measured at test initiation
*5: 95% confidence limits for the LC_{50} expressed as $\mu g/l$ TRC
*6: NOAEL = No Observed Acute Effect Level expressed as $\mu g/l$ TRC
*7: LC_{50} using graphical estimation method

The relative sensitivity of the three test species to TRC was consistent throughout the studies with minnows least sensitive, Ceriodaphnia sp. most sensitive and D. pulex intermediate in sensitivity. The range in LC_{50}s for the minnow tests (using LC_{50}s generated through the Moving Average Angle technique) was 168 to 327 µg/L TRC, and that for D. pulex was 34 to 150 µg/L. Ceriodaphnia sp. LC_{50}s ranged from 22 to 40 µg/L TRC.

Laboratory - Field Comparisons

The chlorine-dosed effluent toxicity tests conducted in the laboratory with fathead minnows were inconsistent predictors of instream impacts to caged minnows. During the first study at the Westborough site, results of laboratory tests with minnows overestimated effects exhibited instream. LC_{50}s (168 and 180 µg/L TRC using Moving Average Angle and graphical estimation techniques, respectively) generated from the laboratory toxicity tests were 200 µg/L below the highest TRC levels measured at the recovery station (247 m) in the field study. In addition, the TRC concentrations at the recovery station in the first study exceeded the 95% confidence limits for the laboratory tests, although only by a small margin (approximately 30 µg/L). Laboratory and field results from the second study conducted at this site were much less dissimilar than those from the first study.

The results of field and laboratory studies conducted for the Belchertown facility were opposite those for the Westborough-Shrewsbury plant. At the former site, laboratory tests with minnows severely underestimated effects exhibited instream. Laboratory-generated LC_{50}s (Moving Average Angle technique) for the first and second studies conducted at the Belchertown site were 274 and 196 µg/L TRC, respectively. Confidence limits for these two LC_{50}s were 230 to 318 µg/L TRC for the first study and 145 to 267 µg/L for the second study. Field study results for this site infer that caged minnows were much more sensitive to TRC than the laboratory tests predicted. Sixty percent of the minnows caged at the 183 m station died in both field studies where measured TRC concentrations were below detectable levels on the first study and only reached 95 µg/L during the second study.

Comparisons between laboratory and field results from the Hopedale study are difficult to make due to the uncertainty in the maximum TRC levels to which minnows were exposed at instream stations. Although this caveat can be attached to any of the data sets since TRC was measured in a discontinuous fashion, it is especially evident at the Hopedale site where a TRC slug was documented. The highest recorded TRC associated with this chlorine slug was at the 244 m station where instream concentrations reached 280 µg/L TRC, but actual instream TRC levels may have been much higher.

DISCUSSION

The toxic effects from chlorine on aquatic life follow a dose-response pattern that is basically similar to that of many other toxicants. The chlorine concentration over the period of exposure as well as the duration of the exposure both affect the ultimate toxicity of this substance. One major difference between this and other toxicants, however, is that dose-response patterns for chlorine as measured by TRC are not uniform except under fairly controlled conditions. This variability in the toxicity of TRC has been related to differential toxicities of each of the various components (free and combined) of TRC in addition to synergy between TRC and certain physicochemical components of the aquatic environment (see Brungs, 1973, and EPA, 1984a for reviews).

In developing the chlorine criteria, the EPA (1984a) evaluated a number of environmental parameters which appeared to alter the toxicity of TRC. They concluded that although some parameters affected the toxicity of TRC in certain cases, there did not seem to be any one parameter that had a universal effect. For example, research on brook trout (Thatcher, et al., 1976) and channel catfish and bluegills (Roseboom and Richey, 1977) indicates that while brook trout and channel catfish are more susceptible to TRC at high temperatures, bluegills are not.

Site-specific differences in the response of caged minnows to TRC in the current study are most apparent when data from the Westborough and Belchertown field studies are compared. The short-term, high intensity surge in TRC at the Hopedale site renders comparisons of the data from this site with those from the other two sites somewhat tenuous. As a result, discussions of differential responses of minnows to TRC will be limited to the studies conducted at the Westborough and Belchertown sites.

Differences in water column temperatures between the two studies conducted at the Belchertown site may have altered the toxicity of TRC from one study to the next. The median water column temperature during the first Belchertown study was about 3 ^{o}C higher than that during the second study. Minnow survival at the 183 m station (the only test station where minnow survival was observed on both studies) was the same (40%) for both field studies. Maximum TRC levels measured at this station did not exceed 30 µg/L on the first study but reached up to 95 µg/L on the second. These results correspond with the idea that chlorine toxicity to fathead minnows increased with temperature.

Temperature, however, could not account for the differences in TRC toxicity observed between the Belchertown and Westborough sites. Water column temperatures at the Westborough site were about the same or slightly higher than those at the Belchertown site. In theory, TRC toxicity should have been the same or slightly greater at the former site if temperature was the driving force behind the large differences in TRC toxicity exhibited at the two sites. This was not the case: caged minnows at the Belchertown site succumbed at much lower TRC levels than did those at the Westborough site.

A more promising explanation for the differences in TRC toxicity between the Westborough and Belchertown sites relates to differences in the levels of dissolved oxygen between the two sites. A number of studies on fish have shown

that chlorine can both denature the structure of the gill as well as impair the ability of hemoglobin in the blood to transport oxygen.

In a study by Wiley (1981), blue rockfish (Sebastes mystinus), a marine species, exhibited distinct deterioration of gill tissue after exposure to chlorine. Fish exposed to TRC pulses of 0.3 mg/L and higher in this study exhibited distortions of epithelium and basement membranes of gill lamellae. In fish exposed to TRC pulses of 0.5 mg/L and higher, the lamellar epithelium became thoroughly separated from supportive structures resulting in tissue necroses. Fish mortality in these studies was attributed to anoxia.

Most of the TRC in Wiley's study with rockfish was composed of free chlorine. Although the different forms of chlorine were not measured in the field studies in the current study, the authors expect that most, if not all, of the TRC observed in the field studies was in the form of chloramines due to the presence of significant quantities of ammonia.

The effect of chloramines on hemoglobin was first studied in humans but later was shown to affect fathead minnows in a similar fashion. Eaton et al. (1973), studied a population of uremic patients undergoing hemodialysis. Hemolytic anemia in these patients was found to be due to the presence of chloramines in the dialysis water. Chloramines were shown to inhibit an enzymatic system that normally protects the red blood cell from oxidants. Anemic patients had substantially elevated levels of methemoglobin, an oxidized form of hemoglobin which cannot transport oxygen and the anemia in these patients was linked to this inability of methemoglobin to supply tissues with oxygen.

In a later study, Grothe and Eaton (1975) evaluated the effects of chloramines on the hemoglobin of fathead minnows. These researchers exposed minnows to short-term, high level (1.5 mg/L) chloramine pulses (primarily monochloramine) and analyzed the blood of control and test groups for methemoglobin concentrations. Approximately 30% of the total hemoglobin taken from treated fish was methemoglobin; methemoglobin levels of control fish was less than 3% of the total hemoglobin. The authors attributed mortality of fish exposed to lethal concentrations of TRC to anoxia through a deterioration of the blood's capacity to carry oxygen to the tissues.

Judging from a study by Brungs (1971) on the effects of low D.O. on fathead minnows, dissolved oxygen concentrations at several of the test stations at the Belchertown site were probably at the critical level for this species while those at the Westborough site were not. In the Brungs study, minnows held in flow-through containers with an oxygen tension of 2.0 mg/L at 23 to 25 ^{o}C (virtually the same temperature range as that in the current study) all died within two weeks. Most died within two to five days. Average fry survival at 3.0 mg/L D.O., was 6% after 30 days while survival of control minnows was 50%. Oxygen concentrations at the Belchertown site at the 183 m station (where there was 40% survival at the end of both field studies) ranged from 2.2 to 3.4 mg/L during the first study and from 2.6 to 4.1 during the second study. D.O. concentrations at the 244 m station at this site were even lower, although minnow survival was slightly (5%) higher. In contrast, water column oxygen concentrations at test stations at the Westborough site were much higher than those at the Belchertown site, and remained above 4.0 mg/L for most of the study.

If TRC adversely affects gill or hemoglobin structure or function in fathead minnows, the rate of oxygen transfer to inner tissues of fish exposed to TRC would be lower than that in non-exposed fish. As a corollary to this, fish exposed to TRC and held at very low D.O. concentrations should succumb to anoxia at a faster rate than fish exposed to similar TRC levels but held at more moderate levels of D.O. This explanation would account for the difference in the response of minnows to TRC at the Westborough and Belchertown sites. As D.O. concentrations at the Belchertown site were very low compared to those at the Westborough site, the rate at which minnows succumbed to anoxia at the former site should have been faster than that at the Westborough site. If the full effect of TRC toxicity to fathead minnows was not manifested over the 24-hr. study period, this situation would have resulted in the appearance of an increased toxicity of TRC at the Belchertown site. Within this scenario, the results of instream studies conducted at the Westborough and Belchertown sites would have been much more similar had they been conducted over a longer time period.

One other explanation for differences in TRC toxicity between sites relates to the concentration of ammonia in the receiving stream. Hermanutz, Allen, and Hedtke (in press) recently conducted studies of the toxicity of TRC and its interaction with ammonia in experimental streams using four species of fish: rainbow trout (Oncorhynchus mykiss), channel catfish (Ictalurus punctatus), bluegill (Lepomis macrochirus), and white sucker (Catostomus commersoni). TRC input in these experiments was kept constant at a different level in each of four streams so that resulting concentrations ranged from 5 to 200 µg/L after mixing. A second treatment was tested in which only bluegills and catfish were exposed to approximately the same range of TRC concentrations supplemented with 3 mg/L ammonia. In each of the studies, fish were deployed for 7 to 19 weeks.

In the studies with TRC only, all four species of fish withstood TRC levels up to 200 µg/L without suffering effects on survival or growth. In the studies with ammonia and TRC, bluegill growth and survival was not affected at TRC levels up to 100 µg/L, but all the catfish exposed to TRC at 24 µg/L TRC or higher died.

Results of the field studies conducted at the Westborough and Belchertown sites seem to parallel those of Hermanutz et al. The ammonia levels at the Westborough site were much lower than those at the Belchertown site. Ammonia concentrations in samples collected from test stations from the Westborough site were less than 0.5 mg/L on both studies conducted at that site. Water column ammonia concentrations in downstream samples from the Belchertown site all exceeded 1.8 mg/L and most were between 2.0 and 3.0 mg/L. Although the ammonia levels at the Belchertown site exceeded EPA water quality standards (EPA, 1986) for acute toxicity, laboratory toxicity tests showed that effluents and mixtures of effluent and receiving waters were not toxic to any of the test organisms. Therefore, ammonia alone could not have caused the impacts observed in the field studies. Both ammonia as well as dissolved oxygen may, thereby, have had an influence on the toxic effects of TRC to fathead minnows in the field studies.

The results of the laboratory toxicity tests do not reflect those of the field studies. Intersite comparisons of TRC toxicity from the effluent toxicity tests show no consistent differences. At first it would appear that these findings refute the idea that high ammonia-nitrogen levels increase TRC toxicity: since there were high ammonia-nitrogen levels in the Belchertown effluents, LC_{50}s for these tests should have been much lower than those from the Westborough site.

Since there are no data on the dissapearance rate of TRC over the course of the laboratory tests, comparisons between studies of the toxicity of TRC cannot be made, however. If the decomposition rate of TRC differed from one study to the next, comparisons of LC_{50} values would not accurately represent differences in TRC toxicity because the time of exposure to TRC would not be the same in each study. As a result, it does not appear that the laboratory toxicity test data can be used to determine if the differences in TRC toxicity between sites were related to ammonia concentrations or to other differences between sites, such as water column dissolved oxygen levels. In order to test the potential interactive effect of ammonia with TRC toxicity to fathead minnows, further experiments would have to be conducted preferably under a flow-through regime.

In addition to variability in the inherent toxicity of TRC, there are two other factors that will influence the impacts of chlorinated wastewaters on aquatic biota in receiving streams: TRC concentration and the rate of TRC extinction. In the field studies conducted for this evaluation, the concentration of TRC in effluents was highly variable. This was in part a function of the chlorination equipment used at each facility. None of the facilities studied had flow-paced chlorinators that were functional at the time these studies were conducted. In addition, two of the three plants evaluated were managed on an 8-hour per day basis. While operators were off-duty, TRC dosing of the effluent remained constant and was not matched with either changes in plant flow (which were substantial) or changes in effluent quality. In consequence, there were several high-level pulses of TRC released to receiving streams while the field studies were in progress.

Chlorine demand as well as chlorine dissipation in municipal wastewaters are both functions of effluent quality, particularly the level of organic solids. Over the years as municipal facilities have upgraded the level of sewage treatment, the solids component, and thus the chlorine demand in wastewaters, has been drastically reduced. Because of this, TRC impacts on receiving streams may have been fairly limited in the past because of the high extinction rates of TRC in effluents that are minimally treated. As improved levels of treatment were achieved, impacts of TRC may have become much more widespread than they were previously.

In general, the methods used in the field studies appear to be useful in documenting the zone of 24-hr acute impacts of TRC to fathead minnows in the field. Data generated from these studies could not, however, be used to generate site-specific TRC limits for the plants that were evaluated. This is due to the high degree of variability in effluent TRC concentrations over each study which precludes the development of clear dose-response relationships between TRC and test organism mortality.

The authors feel that the most judicious approach to the development of TRC limits for chlorinated WWPT effluents is to require dechlorination or alternate disinfection for facilities with IWCs of 10% or greater. In situations where the IWC is lower, facilities could be given the option of either meeting the EPA criteria or providing documentation from instream studies that acute effects in receiving streams do not exist due to the chlorination of wastewaters. The 10% IWC level was chosen because effluent TRC concentrations of at least 0.5 to 1.0 mg/L (and 15 min. contact time) are needed to achieve adequate kill of fecal coliforms in secondary effluents according to operators surveyed in this study. TRC concentrations in areas where the IWC is 10% would thereby range, at a minimum, from 50 to 100 μg/L. Actual instream levels would occasionally be much higher due to unplanned TRC excursions. The authors feel

that under these conditions there is a high probability of producing adverse impacts to biota and a blanket policy requiring dechlorination or alternate disinfection is appropriate for these high-risk situations.

If the methods outlined in this study are to be used on a routine basis for evaluating receiving streams for impacts of TRC, a number of changes should be made. First, the field studies should be conducted under conditions of low instream flow. If this is not practical, TRC levels should be temporarily increased (after approval of the Massachusetts DWPC and the Federal EPA) to provide the same level of TRC after dilution with receiving streams as during periods of low flow. Second, the number of chemical analyses should be reduced. Chemical evaluations of effluents were conducted in these studies to provide data on interactive effects and to determine if chemical constituents of effluents could be linked to mortality of caged minnows. Third, while verification of the toxicity level of prechlorinated effluents is an important component of these studies, laboratory tests with chlorine-dosed tests proved difficult to interpret and should not be used to predict instream effects of TRC.

Diel evaluations of instream D.O. should be a part of each field study. Minnow cages should be tested prior to instream studies to determine the upper limit of water velocity to which the cages can be subjected before minnows succumb to mechanical stress. If a 24-hour strip recorder for effluent TRC could be employed, diel measurements of TRC at instream stations would probably not be needed as the range of effluent TRC fluctuations would be known.

SUMMARY

1. Twenty-four hour survival of fathead minnows deployed in cages downstream of chlorinated WWTP discharges was adversely impacted in all five studies conducted. Because minnow survival in upstream (control) stations was acceptable and unchlorinated effluent samples were found to be nontoxic in the laboratory tests, impacts observed at instream stations were judged to be the result of wastewater chlorination.

2. The zone of observed impacts to minnows was small at the Westborough site, but extensive at the other two sites. At the Westborough site, 24-hour acute effects to minnows were observed 21 m downstream from the discharge. At the Hopedale site, 24-hour acute effects to minnows were observed throughout a zone extending 508 m downstream from the discharge. Instream travel time of wastewaters to non-impacted stations varied from less than 23 minutes at the Westborough site to greater than 2 hours at the Hopedale site.

3. The relationship between instream levels of TRC and minnow survival varied dramatically from site to site. In studies conducted at the Westborough site, minnows exposed to TRC concentrations up to 350 μg/L survived. In studies conducted at the Belchertown site, none of the minnows that were exposed to TRC concentrations in excess of 95 μg/L survived.

4. Differences in TRC toxicity between the Westborough and Belchertown sites may have been associated with water column concentrations of ammonia and/or dissolved oxygen. Other researchers (Grothe and Eaton, 1975) have shown that TRC adversely affects the ability of fathead minnows to respire; in addition,

research on other species of fish has suggested that ammonia increases the toxicity of TRC (Hermanutz, et al., in press). The ammonia levels at the instream test stations at the Belchertown site were fairly high (approximately 1.8 to 3.5 mg/L) and were within the range that Hermanutz, et al. found there to be an interactive effect with TRC toxicity. Minnows succumbed at very low levels of TRC at this site. In addition, D.O. levels at this site were low (1.7 to 3.5 mg/L) and if respiratory function was impaired, minnows would be expected to succumb at a faster rate than those kept in more moderate levels of D.O.

By comparison, ammonia-nitrogen levels at the Westborough site were low (<0.5 mg/L at most stations) and D.O. levels were high (>3.4 mg/L at all test stations). At this site, minnows withstood very high concentrations of TRC without succumbing.

5. Chlorine-dosed effluent tests using fathead minnows were inconsistent predictors of TRC effects to minnows in field studies. In some laboratory studies, LC_{50}s from the effluent tests using minnows were approximately 200 µg/L higher than maximum TRC levels measured at field stations where 100 percent of the minnows died. In other studies, results of field and laboratory evaluations were more closely correlated.

6. The relative sensitivity of test species used in laboratory tests to TRC was consistent throughout the studies with minnows least sensitive, _Ceriodaphnia dubia_ most sensitive and _D. pulex_ intermediate in sensitivity.

7. Effluent chlorine concentrations varied considerably at two of the three study sites. TRC levels in the effluent at one site ranged from 0.33 to 2.9 mg/L over the course of two, 24-hour studies. Poor control of effluent TRC concentrations was probably related to the mechanics of chlorination, variable flows and variable chlorine demand of the wastewaters.

8. The procedures used in these studies appear to be useful in documenting acute effects of TRC to fathead minnows in the field. The authors recommend that if these methods are to be used on a routine basis for permit evaluations, a number of changes should be made. These are outlined in previous sections of this report and emphasize streamlining of field and laboratory analyses.

RECOMMENDATIONS

Based on the investigations conducted during the summer of 1988, the authors feel that aquatic biota are at risk in many of the streams in Massachusetts due to chlorine toxicity. Factors contributing to this conclusion are the level of acute instream impacts observed in these studies due to wastewater chlorination, and the lack of adequate chlorine control at WWTPs. In addition, chlorine dissipation and toxicity were found to be highly variable in these studies. Both of these parameters can affect the intensity and areal extent of impacts due to TRC and have been linked to effluent chemistry which may vary substantially over the normal course of operation at WWTPs.

Wastewater facilities posing the greatest threat to aquatic communities in receiving streams are those with a high IWC. In order to provide protection for those streams most severely impacted by chlorinated discharges, the authors recommend that facilities with an IWC of 10% or greater should either dechlorinate or use an alternate form of disinfection. In higher dilution situations where site-specific conditions do not allow for a zone of passage, or where there is specific knowledge of a sensitive community, the authors also recommend dechlorination or alternate disinfection. In those situations where the IWC is less than 10% but instream levels of TRC exceed the EPA criteria, facilities could be given the option of either complying with the criteria, or providing evidence that there are no acute TRC effects to the aquatic community through an instream evaluation conducted under low flow conditions.

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APPENDIX 1

1988 CHLORINE TOXICITY STUDY

METHOD FOR CALCULATING INSTREAM WASTE CONCENTRATION (IWC)

Instream Waste Concentration is here defined as the approximate proportion of instream flow composed of effluent in each 24-hr. study. Calculation of IWC was performed as follows:

(1) $IWC = Qe/(Qe + Qu)$ where Qe = effluent flow rate; and Qu = upstream flow rate.

Lacking 24-hr. flow data, one can approximate IWC by using 24-hr average concentrations of chloride in the water column at the upstream, effluent and downstream stations. Assume the following:

(2) $Qu + Qe = Qd$ where Qd = the downstream flow rate.

If the following labels are assigned to chloride concentrations:

Cu = upstream chloride concentration
Ce = effluent chloride concentration
Cd = downstream chloride concentration

then equation (2) can be rewritten as follows:

(3) $Cu(Qu) + Ce(Qe) = Cd(Qd)$

Since flow rate (Q) is a volume/time relationship, each side of equation (3) can be multiplied through by the time component of the flow rates. This will yield the following:

(4) $Cu(Vu) + Ce(Ve) = Cd(Vd)$ where V is volume, and subscripts u, e and d are as above.

Equation (4) is in the same format as a chemical mixing equation for a static mode. It can be used to approximate the IWC at an instantaneous point in time by using results of chloride analyses from grab samples taken from the upstream, effluent and downstream stations. By taking 24-hr. composite samples, one can sum the chloride concentrations over time, approximating the 24-hr. average chloride concentration at each station.

1988 CHLORINE TOXICITY STUDY

METHOD FOR CALCULATING INSTREAM WASTE CONCENTRATION (IWC)

The following assumptions are made relative to flow (Q) in equation (3):

$(Qu + Qe)$ = 100% of the 24-hr. avg. downstream flow (i.e., Qd), and this expression is assigned a value of 1;
Qe = x% of the 24-hr. avg. downstream flow, and this unit is assigned a value of x;
Qu = (100% - x%) of the 24-hr. avg. downstream flow; this expression is assigned a value of (1-x).

The substitutions above for Qu, Qe and (Qu + Qe) are used to rewrite equation (3) as follows:

$$Cu(1 - x) + Ce(x) = Cd(1)$$

Solving for x, one gets the following:

$$(5) \quad x = \frac{Cd - Cu}{Ce - Cu}$$

One can now refer back to equation (1) and use the substitutions above in place of upstream, effluent and downstream flows to solve for IWC in terms of x:

$$IWC = x / (x + [1 - x]), \text{ and}$$

$$IWC = x$$

Equation (5) can now be used to solve directly for IWC using only the 24-hr. average chloride concentrations from the upstream, effluent and downstream stations.

APPENDIX 2-A

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

INSTREAM MINNOW TEST DATA

JULY 18-19

PARAMETERS	STATION UPSTREAM	21 m	247 m	424 m	512 m	536 m
Time at Start*1	1137	1210	1235	1255	1310	1330
Clearing Time*1*2	1380	—	180	—	110	—
Water Velocity (m/s)*1	0.03	0.12	0.09	0.18	0.18	0.09
Time at Finish*3	1420	1435	1450	1505	1520	1535
Clearing Time*3*2	>1800	—	210	—	80	—
Water Velocity (m/s)*3	0.03	0.12	0.06	0.18	0.11	0.12
Distance from Effluent (m)	29	21	247	424	512	536
No. Minnows Deployed	20	20	20	20	20	20
No. Minnows Surviving	17	3	16	16	20	16

*1: Measurement taken on start date, July 18
*2: Time (in seconds) to clear inner minnow chamber after introduction of ink
*3: Measurement taken on finish date, July 19

APPENDIX 2-B

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

INSTREAM MINNOW TEST DATA

JULY 19-20

PARAMETERS	STATION					
	UPSTREAM	21 m	247 m	424 m	512 m	536 m
Time at Start*1	1420	1435	1450	1505	1520	1535
Clearing Time*1*2	>1800	--	330	--	170	--
Water Velocity (m/s) *1	0.03	0.12	0.06	0.18	0.15	0.12
Time at Finish*3	1425	1435	1445	1450	1500	1505
Clearing Time*3*2	>1800	--	360	--	160	--
Water Velocity (m/s) *3	0.06	0.21	0.12	0.21	0.27	0.18
Distance from Effluent (m)	29	21	247	424	512	536
No. Minnows Deployed	20	20	20	20	20	20
No. Minnows Surviving	20	4	20	20	20	20

*1: Measurement taken on start date, July 19
*2: Time (in seconds) to clear inner minnow chamber after introduction of ink
*3: Measurement taken on finish date, July 20

APPENDIX 2-C

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

INSTREAM MINNOW TEST DATA

AUGUST 15-16

	STATION									
PARAMETERS	UPSTREAM	8 m	15 m	23 m	30 m	46 m	61 m	91 m	122 m	183 m
Time at Start*1	1115	1130	1145	1201	1208	1225	1234	1250	1255	1310
Clearing Time*1*2	360	--	35	--	22	--	--	--	25	--
Water Velocity (m/s)*1	0.12	0.12	0.30	0.37	0.34	0.24	0.30	0.27	0.4	--
Time at Finish*3	1125	1140	1148	1155	1158	1200	1203	1207	1211	1214
Clearing Time*3*2	180	--	10	--	65	--	--	--	65	--
Water Velocity (m/s)*3	0.06	0.09	0.18	0.34	0.37	0.12	0.30	0.27	0.4	--
Distance from Effluent (m)	23	8	15	23	30	46	61	91	122	183
No. Minnows Deployed	20	20	20	20	20	20	20	20	20	20
No. Minnows Surviving	19	0	0	0	0	0	0	0	0	8

*1: Measurement taken on start date, August 15
*2: Time (in seconds) to clear inner minnow chamber after introduction of ink
*3: Measurement taken on finish date, August 16

APPENDIX 2-D

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

INSTREAM MINNOW TEST DATA

AUGUST 16-17

	STATION										
PARAMETERS	UPSTREAM	8 m	15 m	23 m	30 m	46 m	61 m	91 m	122 m	183 m	244 m
Time at Start*1	1300	1340	1345	1349	1355	1359	1402	1429	1437	1442	1508
Clearing Time*1*2	600	--	120	--	25	--	--	--	22	--	--
Water Velocity (m/s)*1	0.06	0.09	0.18	0.34	0.37	0.12	0.30	0.27	0.43	--	--
Time at Finish*3	1300	1304	1312	1318	1321	1326	1330	1335	1340	1345	1350
Clearing Time*3*2	720	--	168	--	195	--	--	--	132	--	--
Water Velocity (m/s)*3	0.09	0.12	0.24	0.37	0.34	0.15	0.27	0.24	0.37	--	--
Distance from Effluent (m)	23	8	15	23	30	46	61	91	122	183	244
No. Minnows Deployed	20	20	20	20	20	20	20	20	20	20	20
No. Minnows Surviving	18	0	0	0	0	0	0	0	0	8	9

*1: Measurement taken on start date, August 16
*2: Time (in seconds) to clear inner minnow chamber after introduction of ink
*3: Measurement taken on finish date, August 17

APPENDIX 2-E

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

INSTREAM MINNOW TEST DATA

SEPTEMBER 13-14

PARAMETERS	STATION									
	UPSTREAM	15 m	30 m	61 m	91 m	122 m	152 m	244 m	427 m	518 m
Time at Start*1	1115	1130	1150	1210	1230	1240	1300	1315	1400	1335
Clearing Time*1*2	32	--	--	--	55	--	16	61	65	50
Water Velocity (m/s)*1	0.30	0.12	0.09	0.09	0.09	0.09	0.21	0.06	0.03	0.03
Water Depth (m)*1	0.30	0.22	0.28	0.56	0.64	0.51	0.28	0.25	0.43	0.58
Time at Finish*3	1103	1048	1113	1123	1137	1147	1158	1213	1232	1245
Clearing Time*3*2	85	--	--	--	38	--	15	50	58	74
Water Velocity (m/s)*3	0.30	0.12	0.15	0.06	0.06	0.06	0.24	0.03	0.06	0.03
Water Depth (m)*3	0.25	--	0.28	0.58	0.61	0.51	0.30	0.28	0.46	0.61
Distance from Effluent (m)	12	15	30	61	91	122	152	244	427	518
No. Minnows Deployed	30	20	20	20	30	20	20	20	20	20
No. Minnows Surviving	30	0	0	0	1	8	8	13	15	16

*1: Measurement taken on start date, September 13
*2: Time (in seconds) to clear inner minnow chamber after introduction of ink
*3: Measurement taken on finish date, September 14

APPENDIX 3.1

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

TIME-OF-TRAVEL

AUGUST 2*

DISTANCE*1	TRAVEL TIME		
	HRS.	MIN.	SEC.
21	0	1	30
247	0	19	--
424	0	37	--
512	0	46	30
536	0	49	--

* Dye study was conducted when the river height at the upstream station was within 5 cm of the height recorded on July 19, 1988 and results should approximate those existing on the latter date.

*1: Distance from effluent in meters.

APPENDIX 3.2

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME-OF-TRAVEL

AUGUST 15

DISTANCE*1	TRAVEL TIME HRS.	MIN.	SEC.
30	0	2	0
61	0	6	0
91	0	11	0
122	0	14	0
152	0	19	30
183	0	23	0
213	0	30	30
244	0	47	30

*1: Distance from effluent in meters.

APPENDIX 3.3

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME-OF-TRAVEL

SEPTEMBER 12

DISTANCE[*1]	TRAVEL TIME		
	HRS.	MIN.	SEC.
15	0	1	15
30	0	1	30
55	0	4	10
91	0	10	05
122	0	21	28
152	0	30	30
244	0	41	0
335	1	7	40
427	1	31	09
518	2	11	40

*1: Distance from effluent in meters.

APPENDIX 4.1

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP-ASSABET RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: UPSTREAM

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
7/18	1200	24	3.7	5.7
	1505	26	5.1	5.7
	1734	27	5.7	5.8
	2015	24	3.8	6.2
	2305	24	--	5.5
7/19	0150	24	3.5	5.3
	0505	24	3.0	6.0
	0805	23	3.5	6.3
	1219	23	4.2	6.1
	1447	24	4.6	6.7
	1703	24	5.3	7.0
	2140	25	3.2	6.3
7/20	0035	25	3.7	6.9
	0320	25	3.3	6.9
	0610	25	4.2	--
	0825	25	4.3	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.1 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP-ASSABET RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: EFFLUENT

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
7/18	1210	22	6.6	6.6
	1512	22	6.8	6.2
	1743	22	6.7	6.3
	2023	24	5.4	6.4
	2320	24	5.0	5.8
7/19	0200	23	5.0	6.3
	0510	22	--	6.1
	0812	22	5.9	6.4
	1229	22	6.3	6.3
	1453	22	6.7	6.7
	1711	23	6.7	6.8
	2150	23	5.5	6.5
7/20	0035	23	5.8	6.8
	0330	23	6.0	6.8
	0600	23	6.2	--
	0835	22	6.6	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.1 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP-ASSABET RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION 21 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
7/18	1225	22	6.7	5.6
	1522	23	7.7	6.2
	1750	23	6.5	6.4
	2034	24	4.8	6.4
	2330	24	5.3	5.9
7/19	0210	23	5.3	5.7
	0520	23	4.5	6.1
	0823	22	6.1	6.1
	1237	23	6.3	6.3
	1504	23	6.3	6.8
	1719	23	6.2	7.0
	2205	23	5.1	6.7
7/20	0105	23	--	7.1
	0340	23	5.0	6.9
	0620	23	5.8	--
	0842	23	5.7	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.1 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP-ASSABET RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION 247 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
7/18	1240	22	6.6	6.5
	1533	23	7.7	6.4
	1800	23	6.2	6.4
	2055	24	4.9	6.1
	2345	24	3.4	5.7
7/19	0220	23	5.0	6.0
	0530	23	4.3	5.9
	0833	22	4.9	6.1
	1245	23	6.3	6.3
	1514	23	6.3	6.8
	1729	23	6.3	7.0
	2230	23	5.5	6.5
7/20	0115	23	4.3	6.2
	0350	23	5.6	6.9
	0630	24	5.5	--
	0853	23	5.3	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.1 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP-ASSABET RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION 424 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
7/18	1255	23	7.2	6.3
	1545	24	6.9	6.5
	1810	23	6.3	6.3
	2115	23	6.0	5.9
7/19	0000	23	5.1	5.6
	0240	23	4.7	5.7
	0550	23	4.5	6.2
	0846	22	4.8	6.2
	1300	23	6.6	--
	1527	23	6.4	6.8
	1741	23	6.5	7.0
	2245	24	4.9	6.6
7/20	0130	23	4.3	7.3
	0405	23	4.9	--
	0645	24	5.5	--
	0903	23	5.3	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.1 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP-ASSABET RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION 512 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
7/18	1305	23	7.3	6.5
	1554	24	7.3	6.1
	1818	24	7.1	6.3
	2130	24	5.1	6.1
7/19	0015	23	4.4	5.4
	0255	23	5.1	6.0
	0605	23	4.6	6.0
	0858	22	5.0	6.2
	1312	23	6.6	—
	1536	23	6.7	6.9
	1751	22	6.5	6.9
	2245	24	5.7	6.6
7/20	0140	23	5.1	7.3
	0420	—	5.0	—
	0655	24	5.2	—
	0911	23	4.6	—

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.1 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP-ASSABET RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION 536 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
7/18	1320	23	7.5	6.6
	1600	24	7.6	6.7
	1825	24	6.7	6.3
	2142	22	4.4	5.8
7/19	0025	23	4.2	5.4
	0305	23	4.8	6.0
	0610	23	4.3	6.1
	0906	22	4.8	6.2
	1320	23	6.4	--
	1543	23	6.6	6.9
	1800	22	6.5	6.9
	2310	23	4.2	6.6
7/20	0150	23	5.0	7.3
	0430	23	4.6	--
	0705	24	5.3	--
	0919	23	4.7	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.2

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP-LAMPSON BROOK

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: UPSTREAM

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
8/15	1204	23	6.9	7.3
	1446	23	6.2	7.2
	1658	23	6.2	7.2
	1950	22	6.9	7.1
	2215	22	5.9	—
8/16	0022	20	6.0	7.3
	0218	20	6.3	—
	0414	20	6.7	6.8
	0614	19	6.5	—
	0825	19	7.0	—
	1017	19	7.0	6.9
	1420	19	6.9	6.9
	1715	20	6.5	6.9
	2042	20	6.2	7.0
	2227	19	6.5	—
8/17	0021	18	7.1	—
	0223	17	7.0	—
	0440	18	7.2	—
	0620	16	7.4	—
	0723	16	7.4	—
	1110	18	7.7	—

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP-LAMPSON BROOK

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: EFFLUENT

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
8/15	1215	26	4.0	6.9
	1455	26	4.3	6.7
	1705	26	4.2	6.7
	2005	26	3.4	6.7
	2220	26	--	--
8/16	0030	26	2.9	6.9
	0223	25	2.8	--
	0420	24	4.0	6.6
	0618	24	3.5	--
	0830	23	4.1	7.7
	1029	23	4.3	6.9
	1430	23	4.3	6.9
	1725	24	4.0	6.9
	2047	24	3.5	7.0
	2230	24	3.8	--
8/17	0026	22	3.6	--
	0229	22	3.6	--
	0448	22	3.9	--
	0627	21	3.9	--
	0755	22	4.8	--
	0950	22	4.8	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP-LAMPSON BROOK

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 8 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
8/15	1246	25	5.5	7.0
	1507	25	4.9	6.8
	1720	25	5.0	6.8
	2015	25	4.7	--
	2230	24	3.8	7.1
8/16	0036	23	4.2	7.1
	0234	23	4.4	--
	0430	22	4.8	6.9
	0628	21	5.0	--
	0845	21	5.3	8.0
	1037	21	5.2	6.9
	1438	23	4.8	6.9
	1738	25	4.4*4	6.9
	2052	22	4.8	7.2
	2238	21	4.8	--
8/17	0031	21	5.0	--
	0234	20	5.2	--
	0455	19	5.7	--
	0636	18	5.9	--
	0807	19	6.2	--
	1030	19	6.2	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units
*4: Overtitrated

APPENDIX 4.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP-LAMPSON BROOK

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 15 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
8/15	1300	24	4.5	6.9
	1516	25	4.9	6.8
	1735	25	4.5	6.8
	2025	24	4.6	--
	2237	24	4.2	7.1
8/16	0047	23	4.3	7.1
	0242	23	--	--
	0440	22	4.8	6.9
	0638	21	5.1	--
	0855	21	5.4*4	7.1
	1050	21	5.1	6.9
	1510	23	5.0	6.9
	1754	24	4.6	6.8
	2058	22	4.6	--
	2242	22	4.8	--
8/17	0038	21	5.0	--
	0240	20	5.2	--
	0458	19	5.3	--
	0640	18	5.8	--
	0814	19	6.0	--
	1040	19	5.8	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units
*4: Overtitrated

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP-LAMPSON BROOK

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 23 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
8/15	1312	25	4.7	7.1
	1526	25	4.7	6.8
	1745	25	4.4	6.8
	2040	24	6.0	--
	2246	23	4.0	--
8/16	0057	23	4.0	7.1
	0255	23	4.2	--
	0448	22	4.7	6.9
	0647	21	5.1	--
	0905	21	5.2	7.1
	1101	22	5.3	6.9
	1535	23	4.7	7.0
	1811	23	4.7	7.0
	2102	22	4.4	--
	2248	22	4.8	--
8/17	0042	21	4.5	--
	0244	20	5.1	--
	0503	19	5.6	--
	0647	18	6.1	--
	0825	18	6.0	--
	1045	19	5.9	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP-LAMPSON BROOK

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 30 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
8/15	1320	24	4.6	6.8
	1540	25	4.4	6.8
	1800	25	4.3	6.7
	2045	24	4.1	--
	2255	23	3.9	--
8/16	0103	23	6.7	7.1
	0301	23	4.7*4	--
	0458	22	4.5	7.0
	0657	21	4.8	--
	0915	21	5.0	7.1
	1107	22	4.7	6.9
	1552	23	4.5	6.9
	1819	23	4.5	7.0
	2112	22	4.4	--
	2253	21	4.5	--
8/17	0048	21	4.4	--
	0249	20	4.7	--
	0508	19	5.9	--
	0652	18	5.5	--
	0840	19	5.8	--
	1055	19	5.6	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units
*4: Overtitrated

APPENDIX 4.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP-LAMPSON BROOK

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 46 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
8/15	1329	26	4.4	7.1
	1446	26	4.3	6.8
	1658	26	4.2	7.0
	1950	25	4.1	6.7
	2205	24	3.8	7.1
8/16	0020	23	3.1	--
	0220	23	4.0	7.0
	0410	22	4.1	--
	0610	22	4.3	7.3
	0822	22	4.6	7.0
	1020	22	4.9	7.1
	1423	23	4.2	7.2
	1829	23	4.1	6.9
	2040	23	3.5	7.7
	2230	22	4.3	6.7
8/17	0020	21	3.8	--
	0222	19	4.6	--
	0445	18	4.5	--
	0620	18	5.3	--
	0740	18	5.4	--
	1028	20	5.3	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP-LAMPSON BROOK

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 61 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
8/15	1329	25	4.3	6.8
	1510	26	4.1	7.0
	1707	26	3.6	6.9
	2008	25	3.7	6.9
	2226	24	3.7	7.1
8/16	0028	24	3.6	--
	0230	23	3.9	6.9
	0420	22	4.0	--
	0620	22	4.1	7.3
	0830	22	4.5	7.0
	1040	22	4.5	7.1
	1455	23	4.1	6.9
	1842	23	3.9	6.9
	2048	23	3.2	7.6
	2240	22	3.6	--
8/17	0028	21	3.8	--
	0230	19	4.1	--
	0450	18	4.7	--
	0625	18	4.9	--
	0750	18	5.1	--
	1038	20	5.1	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP-LAMPSON BROOK

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 91 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
8/15	1348	26	3.7	7.2
	1520	26	3.8	6.9
	1720	26	3.5	6.9
	2025	24	3.5	7.0
	2240	24	3.4	7.1
8/16	0040	23	3.3	—
	0238	23	3.6	6.6
	0432	22	3.9	—
	0628	21	3.8	7.2
	0838	22	4.2	7.1
	1050	22	4.2	7.1
	1505	23	3.7	6.9
	1854	23	3.4	6.9
	2052	22	3.4	7.5
	2242	22	3.5	—
8/17	0038	19	3.6	—
	0240	19	4.0	—
	0455	18	4.0	—
	0630	18	4.4	—
	0802	18	4.9	—
	1046	20	4.7	—

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP-LAMPSON BROOK

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 122 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
8/15	1405	26	3.3	6.8
	1529	26	3.2	6.9
	1729	26	3.2	6.9
	2041	24	3.2	7.0
	2250	24	3.1	7.1
8/16	0050	24	2.9	--
	0250	23	3.8	6.7
	0445	22	3.6	--
	0640	21	3.4	7.2
	0847	22	4.2	7.1
	1102	22	4.1	7.1
	1513	23	3.8	6.9
	1940	22	3.4	6.9
	2100	22	3.1	7.5
	2253	22	3.3	--
8/17	0042	20	3.6	--
	0245	19	3.9	--
	0505	18	4.0	--
	0638	18	4.9	--
	0814	18	4.7	--
	1054	20	4.6	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP-LAMPSON BROOK

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 183 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
8/15	1415	#1 not done ------------		
	1539	26	2.8	7.1
	1739	26	2.8	6.9
	2047	24	3.4	7.1
	2305	24	2.2	7.1
8/16	0105	23	2.5	--
	0258	23	2.9	6.7
	0455	22	3.0	--
	0650	21	3.1*4	7.3
	0855	22	3.4	7.1
	1111	22	3.2	7.2
	1520	23	2.7	6.9
	1957	23	2.8	7.6
	2108	22	2.8	7.5
	2300	21	2.6	--
8/17	0050	19	2.7	--
	0250	19	3.2	--
	0510	18	3.7	--
	0643	17	3.3	--
	0824	18	4.1	--
	1102	20	3.7	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units
*4: Some air bubbles present

APPENDIX 4.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP-LAMPSON BROOK

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 244 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
8/16	1526	23	2.3	7.0
	2112	22	2.2	7.6
	2209	22	1.7	6.9
	2308	22	--	--
8/17	0055	20	2.0	--
	0255	19	2.1	--
	0515	18	3.0	--
	0650	18	3.1	--
	0830	18	3.4	--
	1108	20	3.3	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.3

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP-MILL RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: UPSTREAM

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
9/13	1120	17	8.0	6.7
	1315	17	8.0	6.8
	1555	20	7.9	--
	1753	18	8.0	6.8
	2010	17	7.3	7.0
	2230	17	7.5	7.5
9/14	0058	16	7.4	7.0
	0315	15	7.6	7.0
	0557	14	7.9	--
	0810	14	6.0	7.0
	1030	14	8.3	7.0

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP-MILL RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: EFFLUENT

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
9/13	1130	19	6.5	--
	1326	19	7.8	--
	1555	20	7.5	--
	1742	20	7.0	--
	1950	19	6.5	--
	2230	19	6.2	7.5
9/14	0040	19	6.3	7.6
	0255	19	6.1	7.5
	0420	--	--	--
	0540	18	6.4	7.4
	0757	18	5.5	--
	1020	18	6.6	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP-MILL RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 15 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
9/13	1138	18	—	—
	1333	19	7.5	—
	1609	18	7.9	—
	1803	19	7.6	—
	2015	18	7.0	—
	2245	18	7.3	—
9/14	0105	17	7.3	7.5
	0320	15	7.6	—
	0600	14	7.7	—
	0815	16	5.4	—
	1040	16	8.2	—

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP-MILL RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN

STATION: 30 m

DATE	TIME	TEMPERATURE*1	D.O.*2
9/13	1151	18	--
	1338	18	7.6
	1615	19	7.8
	1812	19	7.4
	2050	18	7.2
	2255	18	7.4
9/14	0112	16	7.5
	0330	15	7.6
	0610	14	7.9
	0835	16	9.4
	1047	14	7.9

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP-MILL RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 61 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
9/13	1155	18	6.3	6.9
	1345	18	7.8	7.0
	1620	18	7.5	7.1
	1819	19	7.5	6.9
	2100	18	7.1	7.3
	2310	17	7.3	7.4
9/14	0125	16	7.6	7.3
	0335	15	7.5	7.5
	0447	—	—	—
	0623	14	7.6	7.5
	0855	16	6.7	7.2
	1100	15	8.0	7.3

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP-MILL RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN

STATION: 91 m

DATE	TIME	TEMPERATURE*1	D.O.*2
9/13	1205	18	4.5
	1352	18	7.9
	1627	18	7.4
	1826	19	7.5
	2100	18	6.9
	2302	17	7.0
9/14	0112	16	7.4
	0328	15	7.4
	0440	—	—
	0616	14	7.3
	0901	16	6.5
	1105	16	7.8

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l

APPENDIX 4.3

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP-MILL RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 122 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
9/13	1213	17	7.3	7.0
	1324	17	7.9	7.1
	1600	18	4.5	7.0
	1832	19	7.2	7.1
	2130	18	6.8	7.3
	2253	17	7.2	7.2
9/14	0104	16	7.1	7.1
	0321	15	7.2	7.2
	0440	—	—	—
	0609	14	7.4	7.2
	0906	15	6.4	7.3
	1115	15	7.6	7.3

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP-MILL RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN

STATION: 152 m

DATE	TIME	TEMPERATURE*1	D.O.*2
9/13	1120	18	7.5
	1328	18	7.0
	1605	17	7.4
	1754	18	7.6
	2017	18	6.9
	2243	17	7.2
9/14	0104	16	7.3
	0328	15	7.5
	0450	—	—
	0601	14	7.6
	0815	14	7.5
	1108	15	5.2

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l

APPENDIX 4.3

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP-MILL RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 244 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
9/13	1130	18	7.7	--
	1331	18	7.2	7.1
	1612	17	7.6	7.0
	1759	18	7.4	7.0
	2033	18	6.8	7.2
	2250	17	7.0	7.1
9/14	0058	16	7.3	7.1
	0320	15	7.4	7.1
	0450	--	--	--
	0600	14	7.6	7.2
	0830	14	7.2	7.3
	1100	15	6.6	7.4
	1200	--	--	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 4.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP-MILL RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN

STATION: 427 m

DATE	TIME	TEMPERATURE*1	D.O.*2
9/13	1145	18	7.7
	1402	16	7.2
	1630	17	7.6
	1810	18	7.3
	2052	17	6.8
	2300	17	6.9
9/14	0100	16	7.0
	0320	15	7.1
	0500	--	--
	0610	14	7.1
	0850	14	7.3
	0920	--	--
	1050	15	7.4
	1217	--	--

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME, TEMPERATURE, DISSOLVED OXYGEN, pH

STATION: 518 m

DATE	TIME	TEMPERATURE*1	D.O.*2	pH*3
9/13	1150	—	7.5	7.3
	1355	18	7.3	7.0
	1641	—	7.5	7.0
	1817	18	7.8	7.1
	2114	17	7.1	7.1
9/14	0058	17	6.9	7.1
	0320	16	6.7	7.2
	0450	15	6.7	7.1
	0600	14	7.0	—
	0858	14	7.0	7.1
	0938	—	—	—
	1037	14	5.4	7.0
	1224	—	—	—

*1: Degrees centigrade
*2: Dissolved oxygen in mg/l
*3: Standard units

APPENDIX 5-A

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

WATER CHEMISTRY*1

JULY 18-19
(units in mg/l except where noted otherwise)

	STATION						
PARAMETER	UPSTREAM	EFFLUENT	21 m	247 m	424 m	512 m	516 m
Hardness	50	81	70	74	81	74	74
Suspended Solids	4.0	2.0	3.5	2.5	3.5	9.0	6.5
Total Solids	300	410	500	520	430	450	420
Specific Conductance*2	900	710	1283	1423	990	1014	931
Total Kjeldahl-N	2.0	3.2	1.0	2.0	3.2	3.0	1.7
Ammonia-N	0.09	0.15	0.07	0.18	0.47	0.16	0.08
Nitrate-N	0.5	3.9	3.4	2.8	5.6	3.2	3.0
Total-P	0.29	7.3	6.1	6.1	6.0	6.0	6.4
Chloride	21	90	83	80	78	80	78
TOC*3	16	18	17	17	17	17	16

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs. Results reported in µg/L.

*2: Results reported in µmho/cm.

*3: Total organic carbon

APPENDIX 5-B

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

WATER CHEMISTRY*1

JULY 19-20
(units in mg/l except where noted otherwise)

	STATION								
PARAMETER	UP-STREAM	EFFLUENT	DUPLICATE EFFLUENT	21 m	247 m	424 m	DUPLICATE 424 m	512 m	536 m
Hardness	53	99	99	86	—	81	75	80	80
Suspended Solids	5.0	1.5	1.5	5.5	6.0	2.5	—	4.5	3.0
Total Solids	220	524	504	70	360	420	—	440	420
Specific Conductance*2	362	861	848	670	547	808	—	848	780
Total Kjeldahl-N	0.76	1.5	2.0	1.5	2.0	4.2	1.9	4.2	4.0
Ammonia-N	0.26	0.03	0.04	0.08	0.13	0.25	0.12	0.17	0.14
Nitrate-N	0.4	4.0	4.3	3.4	3.1	3.7	2.7	3.2	3.0
Total-P	0.35	4.6	4.8	4.0	3.7	3.4	3.5	3.3	3.1
Chloride	27	120	120	100	93	90	—	90	93
TOC*3	15	17	—	16	15	15	—	15	16

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs; instream sampling was conducted every 2-3 hrs. Results reported in µg/l.

*2: Results reported in µmho/cm.

*3: Total organic carbon

APPENDIX 5-C

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

WATER CHEMISTRY*1

AUGUST 15-16
(units in mg/l except where noted otherwise)

	STATION											
PARAMETER	UP-STREAM	EFFLUENT	DUPL. EFFL.	8 m	15 m	23 m	30 m	46 m	61 m	91 m	122 m	183 m
Alkalinity	57	76	--	72	71	70	67	--	68	66	69	67
Hardness	95	62	54	79	78	79	78	78	78	79	81	79
Suspended Solids	2.0	7.5	--	3.0	2.5	3.0	3.0	--	3.0	5.0	5.0	4.0
Total Solids	260	270	--	260	250	270	300	--	300	270	250	260
Specific Conductance*2	448	475	--	482	484	480	487	--	482	484	485	484
Total Kjeldahl-N	0.8	10.0	7.7	4.6	4.6	4.6	4.6	4.6	5.3	4.8	4.8	4.7
Nitrate-N	--	--	--	--	--	--	--	--	0.8	0.5	1.1	1.0
Ammonia-N	0.15	4.6	5.4	3.0	3.2	2.8	2.8	1.8	2.0	2.7	2.6	2.6
Ortho-P	0.07	4.0	4.0	2.3	2.4	2.2	2.2	2.2	2.2	2.0	2.2	2.0
Total-P	0.1	6.4	6.2	2.6	2.5	2.4	2.4	2.6	3.0	3.2	3.2	3.2
Chloride	80	62	--	75	74	75	70	--	75	75	75	75
TOC*3	17	26	--	23	23	21	21	22	22	22	22	21

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs.
*2: Results reported in µmho/cm
*3: Total organic carbon

APPENDIX 5-D

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

WATER CHEMISTRY*1

AUGUST 16-17
(units in mg/l except where noted otherwise)

PARAMETER	STATION													
	UP	UP-D	EFF	EFF-D	8 m	15 m	23 m	30 m	46 m	61 m	91 m	122 m	183 m	244 m
Alkalinity	58	58	78	80	78	74	72	73	73	73	72	72	69	68
Hardness	96	97	66	68	79	80	79	79	79	76	79	79	81	81
Suspended Solids	<1.0	1.0	3.0	3.0	3.0	2.5	<1.0	2.5	<1.0	2.0	3.5	<1.0	1.0	4.5
Total Solids	270	270	260	260	270	260	260	280	270	270	280	250	270	270
Specific Conductance*2	478	480	469	467	490	489	487	487	487	488	489	489	490	490
Total Kjeldahl-N	1.50	1.10	6.80	5.70	3.80	3.90	3.40	3.90	3.90	4.00	3.60	3.20	3.00	3.20
Ammonia-N	0.18	0.18	5.50	5.50	3.50	2.70	3.10	2.70	3.10	3.10	2.70	3.00	3.00	2.50
Ortho-P	0.12	0.14	4.00	4.00	2.40	2.40	2.40	2.20	2.20	2.30	2.30	2.30	2.40	2.30
Total-P	0.22	0.22	5.80	5.20	2.50	2.50	2.60	2.60	2.50	2.50	2.80	3.00	3.10	3.30
Chloride	90	89	61	62	80	80	79	80	80	81	80	79	80	77
TOC*3	18	--	26	--	23	24	23	22	23	22	22	23	22	22

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs.
*2: Results reported in µmho/cm.
*3: Total organic carbon

APPENDIX 5-E

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

WATER CHEMISTRY*1

SEPTEMBER 13-14
(units in mg/l except where noted otherwise)

	STATION								
PARAMETER	UPSTREAM	DUPLICATE UPSTREAM	EFFLUENT	DUPLICATE EFFLUENT	61 m	122 m	244 m	518 m	DUPLICATE 518 m
Alkalinity	18	--	152	169	15	--	--	--	--
Hardness	33	33	43	45	35	35	35	35	34
Suspended Solids	5.0	4.5	8.0	8.5	8.5	10.0	7.5	8.0	7.0
Total Solids	140	210	720	760	280	400	300	370	300
Specific Conductance*2	221	568	974	969	418	1044	543	921	446
Total Kjeldahl-N	1.5	1.6	5.4	5.5	2.5	2.2	2.0	1.9	1.7
Ammonia-N	0.06	0.05	0.10	0.11	0.07	0.06	0.06	0.05	0.08
Ortho-P	0.02	0.01	0.99	1.00	0.13	0.10	0.09	0.13	0.15
Total-P	0.08	0.08	1.20	1.20	0.30	0.32	0.35	0.32	0.32
Chloride	44	44	60	60	48	48	48	48	46

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs.

*2: Results reported in µmho/cm.

APPENDIX 6-A

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

TOTAL METALS*1 (mg/l)

JULY 18-19

PARAMETER	STATION						
	UPSTREAM	EFFLUENT	21 M	247 m	424 m	512 m	536 m
Ag*2	ND	ND	ND	ND	ND	ND	ND
Al*3	ND	ND	ND	ND	ND	ND	ND
Cd*2	ND	ND	ND	ND	ND	ND	ND
Cr*4	ND	ND	ND	ND	ND	ND	ND
Cu	0.05	0.05	0.06	0.05	0.06	0.04	0.04
Mn*5	0.14	ND	0.05	0.06	0.06	0.05	0.05
Ni*4	ND	ND	ND	ND	0.03	ND	ND
Pb*6	0.02	ND	0.002	ND	0.002	ND	ND
Zn*5	<0.02	0.05	0.03	0.05	0.06	0.06	0.03

*1: All samples were 24-hr. composites of equal volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs.
*2: ND (not detected) = less than 0.001 mg/l
*3: ND = less than 0.1 mg/l
*4: ND = less than 0.03 mg/l
*5: ND = less than 0.02 mg/l
*6: ND = less than 0.002 mg/l

APPENDIX 6-B

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

TOTAL METALS*1 (mg/l)

JULY 19-20

	STATION								
PARAMETER	UP-STREAM	EFFLUENT	DUPLICATE EFFLUENT	21 m	DUPLICATE 21 m	247 m	424 m	512 m	536 m
Ag*2	ND	ND	ND	ND	ND	ND	ND	ND	ND
Al*3	ND	0.23	ND	0.23	ND	0.13	0.12	0.1	ND
Cd*2	ND	ND	0.001	ND	ND	0.001	ND	ND	ND
Cr*4	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cu	0.02	0.04	0.03	0.05	0.07	0.1	0.05	0.04	0.04
Mn*5	0.23	0.02	ND	0.26	0.06	0.07	0.07	0.05	0.06
Ni*4	ND	ND	ND	ND	ND	ND	ND	ND	—
Zn	0.03	0.29	0.17	0.23	0.06	0.33	0.09	0.06	0.06

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs.
*2: ND (not detected) = less than 0.001 mg/l
*3: ND = less than 0.1 mg/l
*4: ND = less than 0.03 mg/l
*5: ND = less than 0.02 mg/l
*6: ND = less than 0.002 mg/l

APPENDIX 6-C

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TOTAL METALS*1 (mg/l)

AUGUST 15-16

	STATION											
PARAMETER	UP-STREAM	EFFL.	DUPL. EFFL.	8 m	15 m	23 m	30 m	46 m	61 m	91 m	122 m	183 m
Ag*2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Al*3	BDL	0.13	BDL	BDL	BDL	0.45	0.27	BDL	BDL	BDL	BDL	0.15
Cd*2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cr*4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cu	0.1	0.02	0.05	0.02	0.03	0.02	0.02	0.02	0.05	0.08	0.07	0.06
Fe	0.45	0.22	0.21	0.55	0.58	0.63	0.52	0.4	0.4	0.19	0.55	0.47
Ni*4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.06	BDL	BDL
Pb	0.06	0.009	0.007	0.003	0.01	0.005	0.004	0.002	0.002	0.009	0.005	0.004
Zn*5	0.15	BDL	0.02	BDL	0.05	BDL	BDL	BDL	0.07	0.05	0.03	0.03

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs.
*2: BDL (below detection limit) = <0.001 mg/L
*3: BDL = <0.1 mg/L
*4: BDL = <0.03 mg/L
*5: BDL = <0.02 mg/L

APPENDIX 6-D

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TOTAL METALS*1 mg/l

AUGUST 16-17

	STATION													
PARAMETER	UP-STREAM	DUPL. UPSTR.	EFFL.	DUPL. EFFL.	8 m	15 m	23 m	30 m	46 m	61 m	91 m	122 m	183 m	244 m
Ag*2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.001	BDL	BDL	BDL	BDL	BDL	BDL
Al*3	0.13	BDL	BDL	BDL	0.12	BDL	BDL	BDL	BDL	0.2	BDL	BDL	BDL	BDL
Cd*2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cr*4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cu	0.017	0.015	0.039	0.1	0.019	0.017	0.05	0.05	0.029	0.028	0.032	0.024	0.018	0.015
Fe	0.39	0.68	0.34	0.17	0.43	0.44	0.41	0.72	0.45	0.47	0.57	0.43	0.46	0.44
Ni*4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pb	0.004	0.01	0.003	0.15	0.006	0.003	0.006	0.022	0.017	0.004	0.009	0.005	0.006	0.002
Zn*5	BDL	BDL	0.06	0.06	0.05	0.03	0.03	0.05	0.02	0.05	0.02	0.02	BDL	BDL

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs; instream sampling was conducted every 2-3 hrs.
*2: BDL (below detection limit) = <.001
*3: BDL = <0.1 mg/L
*4: BDL = <0.03 mg/L
*5: BDL = <0.02 mg/L

APPENDIX 6-E

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TOTAL METALS*1 (mg/l)

SEPTEMBER 13-14

PARAMETER	STATION							
	UPSTREAM	DUPLICATE UPSTREAM	EFFLUENT	DUPLICATE EFFLUENT	61 m	122 m	244 m	518 m
Ag*2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Al*3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cd*2	BDL	BLD	BLD	0.002	BDL	BDL	BDL	BDL
Cr*4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cu	0.012	0.008	0.013	0.012	0.011	0.009	0.009	0.01
Mn	1.2	1.2	1.4	1.3	1.2	1.2	1.2	1.2
Ni*4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pb*5	0.004	0.004	BDL	BDL	0.004	0.003	0.004	0.004
Zn	0.03	0.03	0.04	0.03	0.06	0.06	0.03	0.03

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs.
*2: BDL (below detection limit) = <0.001 mg/L
*3: BDL = <0.1 mg/L
*4: BDL = <0.03 mg/L

APPENDIX 7-A

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

DISSOLVED METALS*1 (mg/l)

JULY 18-19

	STATION						
PARAMETER	UP-STREAM	EFFLUENT	21 m	DUPLICATE 21 m	247 m	424 m	512 m
Ag*2	ND	ND	ND	ND	ND	ND	ND
Al*3	ND	ND	ND	ND	ND	ND	ND
Cd*2	ND	ND	ND	ND	ND	ND	ND
Cr*4	ND	ND	ND	ND	ND	ND	ND
Cu	0.03	0.02	0.03	0.03	0.04	0.02	0.03
Mn	0.04	0.15	0.04	0.04	0.05	0.07	0.05
Ni*4	ND	ND	ND	ND	ND	ND	ND
Pb*5	ND	ND	ND	0.002	0.005	0.003	0.004
Zn	0.03	0.05	0.11	0.05	0.06	0.04	0.04

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs.
*2: ND (not detected) = <0.001 mg/l
*3: ND = <0.1 mg/l
*4: ND = <0.03 mg/l
*5: ND = <0.002 mg/l

APPENDIX 7-B

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

DISSOLVED METALS*1 (mg/l)

JULY 19-20

	STATION									
	UP-		DUPLICATE		DUPLICATE			DUPLICATE		
PARAMETER	STREAM	EFFLUENT	EFFLUENT	21 m	21 m	247 m	424 m	424 m	512 m	536 m
Ag*2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Al*3	ND	ND	0.19	ND	ND	ND	ND	ND	ND	ND
Cd*2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cr*4	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.03
Cu	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mn*5	0.23	ND	ND	0.05	0.25	0.05	0.06	0.05	0.07	0.05
Ni*4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pb*6	ND	ND	0.012	0.002	0.013	ND	ND	ND	ND	ND
Zn*5	ND	0.06	0.17	0.07	0.16	0.05	0.06	0.05	0.04	0.04

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs; instream sampling was conducted every 2-3 hrs.
*2: ND (not detected) = <0.001 mg/l
*3: ND = <0.1 mg/l
*4: ND = <0.03 mg/l
*5: ND = <0.02 mg/l
*6: ND = less than 0.002 mg/l

APPENDIX 7-C

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

DISSOLVED METALS*1 (mg/l)

AUGUST 15-16

PARAMETER	STATION: UP-STREAM	DUPL. UPSTR.	EFFLUENT	DUPL. EFFL.	15 m	23 m	46 m	61 m	91 m	122 m	183 m
Ag*2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Al*3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cd*2	BDL	BDL	BDL	BDL	BDL	0.007	BDL	BDL	BDL	BDL	BDL
Cr*4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cu	<0.004	<0.004	<0.004	0.005	0.021	0.014	0.05	0.004	<0.004	0.004	0.006
Fe	0.14	0.14	0.09	0.06	0.13	0.13	0.13	0.14	0.12	0.15	0.1
Ni*4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pb*5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Zn*6	BDL	BDL	0.02	BDL	BDL	0.11	0.02	0.03	BDL	BDL	BDL

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs.
*2: BDL (below detection limit) = <0.001 mg/l
*3: BDL <0.1 mg/l
*4: BDL <0.03 mg/l
*5: BDL <0.002 mg/l
*6: BDL <0.02 mg/l

APPENDIX 7-D

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

DISSOLVED METALS*1 (mg/l)

AUGUST 16-17

PARAMETER	STATION												
	UP-STREAM	EFFLUENT	DUPL. EFFL.	8 m	15 m	23 m	30 m	46 m	61 m	91 m	122 m	183 m	244 m
Ag*2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Al*3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cd*4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cr*5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cu*6	BDL	0.003	BDL	0.004	0.004	0.004	0.004	0.006	BDL	BDL	BDL	BDL	BDL
Fe	0.19	0.11	0.11	0.19	0.19	0.20	0.18	0.23	0.24	0.22	0.23	0.22	0.22
Ni*5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pb*4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Zn*7	0.02	0.02	0.02	--	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.02	BDL

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs.
*2: BDL (below detection limit) = <0.001 mg/l
*3: BDL = <0.1 mg/l
*4: BDL = <0.002 mg/l
*5: BDL = <0.03 mg/l
*6: BDL = <0.004 mg/l
*7: BDL = <0.02 mg/l

APPENDIX 7-E

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

DISSOLVED METALS*1 (mg/l)

SEPTEMBER 13-14

	STATION						
PARAMETER	UPSTREAM	DUPLICATE EFFLUENT	EFFLUENT	61 m	122 m	244 m	518 m
Ag*2	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Al*3	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cd*2	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cr*4	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cu	0.002	0.003	0.002	0.006	0.005	0.007	0.007
Fe	0.83	<0.03	<0.03	0.53	1.2	0.56	0.63
Ni*4	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pb*5	0.002	BDL	BDL	BDL	0.003	BDL	BDL
Zn*6	0.03	0.04	0.02	BDL	0.03	0.03	0.02

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs; instream sampling was conducted every 2-3 hrs.
*2: BDL (below detection limit) = <0.001 mg/l
*3: BDL = <0.1 mg/l
*4: BDL = <0.03 mg/l
*5: BDL = <0.002 mg/l
*6: BDL = <0.02 mg/l

APPENDIX 8-A

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

PURGEABLE ORGANIC COMPOUNDS*1 (µg/l)

JULY 19

PARAMETER	STATION						
	UPSTREAM	EFFLUENT*2	21 m	247 m	424 m	512 m	536 m
Purgeable Organics	—	ND*3	—	—	—	—	—
Chloroform	LI*4	—	54	13	13	13	12
Bromodi-chloromethane	LI	—	4.3	10	9.3	8.8	9.0
Methylene chloride	—	—	15	—	—	—	—
1,1-dichloro-ethylene	—	—	1.6	—	—	—	—
1,1-dichloro-ethylene	—	—	LI	—	—	—	—
1,2-dichloro-ethylene	—	—	5.4	—	—	—	—
Trichloroethyne	—	—	1.2	—	—	—	—
Benzene	—	—	LI	—	—	—	—
Dibromochloro-methane	—	—	2.0	3.8	3.4	3.2	3.2

*1: All samples collected were grab samples except where noted.
*2: Effluent sample composited every 0.25 hrs.
*3: ND = not detected
*4: LI = less than 1.0 µg/l

APPENDIX 8-B

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

PURGEABLE ORGANIC COMPOUNDS*1 (µg/l)

JULY 20

	STATION						
PARAMETER	UPSTREAM	EFFLUENT	21 m	247 M	424 M	512 m	536 m
Purgeable Organics	ND*2	--	--	--	--	--	--
Chloroform	--	1.8	1.5	1.4	1.6	1.8	1.6
Bromodi-chloromethane	--	9.8	6.4	6.2	7.6	8.2	6.0
Dibromochloro-methane	--	17	13	12	11	13	9.8
Bromoform	--	19	13	12	10	12	9.5

*1: All samples collected were grab samples.
*2: ND = not detected

APPENDIX 8-C

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

PURGEABLE ORGANIC COMPOUNDS*1 (µg/l)

AUGUST 16

	STATION										
PARAMETER	UP-STREAM	EFFLUENT	8 m	15 m	23 m	30 m	46 m	61 m	91 m	122 m	183 m
Purgeable Organics	ND*2	--	--	--	--	--	ND	ND	ND	ND	ND
1,1-dichloro-ethane	--	LI	--	--	--	--	--	--	--	--	--
Methyl tert butyl ether	--	3.2	2.0	2.8	3.2	5.7	--	--	--	--	--
Trichloro-ethylene	--	LI	LI	LI	LI	LI	--	--	--	--	--
Methyl-chloride	--	--	4.4	3.8	4.4	5.7	--	--	--	--	--
1,2-dichloro-ethylene	--	--	LI	1.8	2.1	3.3	--	--	--	--	--
Chloroform	--	--	--	LI	LI	LI	--	--	--	--	--

*1: All samples collected were grab samples.
*2: ND = Not detected
*3: LI = less than 1.0 µg/l

APPENDIX 8-D

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

PURGEABLE ORGANIC COMPOUNDS*1 (µg/l)

AUGUST 17

PARAMETER	STATION 15 m	23 m	30 m	46 m	61 m	91 m	122 m	183 m	244 m
Purgeable Organics	--	--	--	ND*2	ND	ND	ND	ND	ND
1,1-dichloro-ethylene	L1*3	L1	--	--	--	--	--	--	--
1,1-dichloro-ethane	L1	--	--	--	--	--	--	--	--
1,2-dichloro-ethylene	2.5	1.3	--	--	--	--	--	--	--
Methyl tert. butyl ether	4.0	2.0	--	--	--	--	--	--	--
Trichloro-ethylene	L1	L1	--	--	--	--	--	--	--

*1: All samples collected were grab samples.
*2: ND = Not detected
*3: L1 = less than 1.0 µg/l

APPENDIX 8-E

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

PURGEABLE ORGANIC COMPOUNDS*1 (µg/l)

SEPTEMBER 13-14

	STATION						
PARAMETER	UPSTREAM	DUPLICATE UPSTREAM	EFFLUENT	61 m	122 m	244 m	518 m
Trichloroethylene	1.0	1.1	—	L1*2	L1	L1	L1
Chloroform	—	—	9.2	3.1	1.8	1.8	10
Bromodichloro-methane	—	—	1.8	L1	L1	L1	1.9

*1: All samples were taken from 24-hr. composites.
*2: L1 = less than 1.0 µg/l.

APPENDIX 9-A

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

ACID & BASE NEUTRAL EXTRACTABLES*1 (µg/l)

JULY 18-19

	STATION				
PARAMETER	UPSTREAM	EFFLUENT	21 m	247 m	424 m
N,N-diethylmethyl-benzamide (small peak)	*2	—	*2	*2	—
Tripropenyltriazinet-rione	—	*2	—	—	—
Dipropenylurea	—	*2	—	—	—
Butoxyethoxyethanol acetate (very large peak)	—	*2	—	—	—
Acid Extractables	—	—	—	—	ND
Base/Neutral Extractables	—	—	—	—	ND

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs; instream sampling was conducted every 2-3 hrs.

*2: No standard available for quantification.

ND = Not detected

APPENDIX 9-B

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

ACID & BASE NEUTRAL EXTRACTABLES*1 (µg/l)

JULY 19-20

	STATION						
					DUPLICATE		
PARAMETER	UPSTREAM	EFFLUENT	EFFLUENT-D	21 m	21 m	247 m	424 m
Acid Extractables	ND	--	--	ND	ND	ND	ND
Base/Neutral Extractables	ND	--	--	ND	ND	ND	ND
Tripropenyl-triazinetrione	--	*2	--	--	--	--	--
Butoxyethoxy-ethanol acetate	--	*2	*2 (large peak)	--	--	--	--

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs.

*2: No standard available for quantification.

ND = Not detected

APPENDIX 9-C

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

ACID & BASE NETURAL EXTRACTABLES[*1] (µg/l)

AUGUST 15-16

STATION	ACID EXTRACTABLES	BASE/NEUTRAL EXTRACTABLES
Upstream	ND[*2]	ND
Effluent	ND	ND
Duplicate Effluent	ND	ND
8 m	ND	ND
15 m	ND	ND
21 m	ND	ND
30 m	ND	ND
46 m	ND	ND
61 m	ND	ND
91 m	ND	ND
122 m	ND	ND
183 m	ND	ND
244 m	ND	ND

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs; instream sampling was conducted every 2-3 hrs.
*2: ND = Not detected

APPENDIX 9-D

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

ACID AND BASE NEUTRAL EXTRACTABLES*1 (µg/l)

AUGUST 16-17

STATION	ACID EXTRACTABLES	BASE/NEUTRAL EXTRACTABLES
Upstream	ND*2	ND
Effluent	ND	ND
15 m	ND	ND
30 m	ND	ND
244 m	ND	ND

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs; instream sampling was conducted every 2-3 hrs.

*2: ND = Not detected

APPENDIX 9-E

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

ACID & BASE NEUTRAL EXTRACTABLES*1 (μg/l)

SEPTEMBER 13-14

PARAMETER	STATION					
	UPSTREAM	EFFLUENT	61 m	122 m	244 m	518 m
Acid Extractables	--	--	--	--	--	ND
Base/Neutral Extractables	--	ND*3	--	--	--	ND
Dimethyl, phenylmethyl benzene	*2	--	*2	*2	*2	--
Methyl-pyrrolidinone	--	*2	*2	*2	*2	--
Phenyl-propenal	--	--	--	--	*2	--

*1: All samples were 24-hr. composites of equal-volume subsamples. Effluent sampling was conducted every 0.25 hrs.; instream sampling was conducted every 2-3 hrs.
*2: No standard available for quantification.
*3: ND = Not detected

APPENDIX 10.1

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: UPSTREAM

DATE	TIME	TRC TITRATIONS 1	2	3
7/18/88	1200	ND*2	ND	ND
	1505	ND	ND	ND
	1734	ND	ND	ND
	2015	ND	ND	ND
	2305	ND	ND	--
7/19/88	0150	ND	ND	--
	0505	ND	ND	--
	0805	ND	ND	ND
	1219	ND	ND	ND
	1447	ND	ND	ND
	1703	ND	ND	ND
	2140	ND	ND	--
7/20/88	0035	ND	ND	--
	0320	ND	ND	--
	0610	ND	ND	--
	0825	ND	ND	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.1 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: EFFLUENT

DATE	TIME	TRC TITRATIONS 1	2	3	4	5
7/18/88	1210	0.47	0.41	0.36	0.35	0.36
	1512	0.36	0.36	0.34	--	--
	1743	0.42	0.40	0.40	--	--
	2023	0.56	0.52	0.52	0.51	--
	2320	0.58	0.54	0.53	0.53	--
7/19/88	0200	0.53	0.50	0.50	--	--
	0510	0.42	0.40	0.40	--	--
	0812	0.50	0.48	0.47	0.48	--
	1229	0.61	0.57	0.55	0.58	--
	1453	0.56	0.56	0.55	--	--
	1711	0.62	0.64	0.64	0.65	--
	2150	0.68	0.73	0.72	0.72	--
7/20/88	0035	0.68	0.69	0.69	--	--
	0330	0.56	0.54	0.56	--	--
	0600	0.51	0.51	--	--	--
	0835	0.60	0.59	0.60	--	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985).

APPENDIX 10.1 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 21 m

DATE	TIME	TRC TITRATIONS 1	2	3	4
7/18/88	1225	0.25	0.21	0.21	--
	1522	0.25	0.21	0.21	--
	1750	0.28	0.25	0.25	--
	2034	0.38	0.37	0.38	--
	2330	0.36	0.35	0.36	0.34
7/19/88	0210	0.35	0.35	0.34	--
	0520	0.22	0.19	0.20	--
	0823	0.39	0.41	0.41	--
	1237	0.42	0.46	0.45	--
	1504	0.41	0.41	0.40	--
	1719	0.41	0.45	0.45	0.46
	2205	0.59	0.56	0.54	0.56
7/20/88	0105	0.45	0.47	0.46	--
	0340	0.40	0.35	0.34	0.34
	0620	0.35	0.33	0.33	--
	0842	0.35	0.33	0.33	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985).

APPENDIX 10.1 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 247 m

DATE	TIME	TRC TITRATIONS 1	2	3
7/18/88	1240	0.10	0.10	0.10
	1533	0.13	0.11	0.11
	1800	0.11	0.12	0.11
	2055	0.24	0.23	0.22
	2345	0.26	0.26	0.24
7/19/88	0220	0.24	0.23	0.23
	0530	0.14	0.13	0.15
	0833	0.15	0.14	0.13
	1245	0.35	0.34	0.35
	1514	0.27	0.29	0.28
	1729	0.26	0.26	0.26
	2230	0.38	0.38	0.39
7/20/88	0115	0.34	0.32	0.33
	0350	0.25	0.25	0.25
	0630	0.06	0.05	0.06
	0853	0.11	0.11	0.10

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985).

APPENDIX 10.1 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 424 m

DATE	TIME	TRC TITRATIONS 1	2	3	4
7/18/88	1255	0.07	0.07	0.07	--
	1545	0.06	0.04	0.06	--
	1810	0.07	0.07	0.07	--
	2115	0.13	0.13	0.14	--
7/19/88	0000	0.21	0.19	0.20	0.19
	0240	0.12	0.16	0.16	--
	0550	0.12	0.10	0.11	--
	0846	0.06	0.07	0.06	--
	1300	0.22	0.25	0.24	--
	1527	0.21	0.20	0.20	--
	1741	0.19	0.20	0.18	--
	2245	0.30	0.31	0.29	--
7/20/88	0130	0.25	0.25	0.25	--
	0405	0.30	0.19	0.20	0.20
	0645	ND*2	ND	ND	ND
	0903	ND	0.03	0.03	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not dectected; TRC <0.03 mg/l

APPENDIX 10.1 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 512 m

DATE	TIME	TRC TITRATIONS 1	2	3	4
7/18/88	1305	0.04	0.05	0.05	--
	1554	0.04	0.02	0.03	--
	1818	0.06	0.05	0.05	--
	2130	0.07	0.09	0.10	0.10
7/19/88	0015	0.14	0.17	0.15	0.16
	0255	0.14	0.26	0.13	0.13
	0605	0.11	0.08	0.09	--
	0858	0.06	0.04	0.04	--
	1312	0.21	0.21	0.21	--
	1536	0.13	0.14	0.13	--
	1751	0.14	0.14	0.13	--
	2245	0.21	0.25	0.25	--
7/20/88	0140	0.21	0.23	0.22	--
	0420	0.20	0.16	0.18	0.17
	0655	ND*2	ND	--	--
	0911	ND	ND	ND	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.1 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

WESTBOROUGH WWTP - ASSABET RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 536 m

DATE	TIME	TRC TITRATIONS 1	2	3	4
7/18/88	1320	0.05	0.04	0.04	--
	1600	0.04	0.02	0.02	--
	1825	0.04	0.05	0.04	--
	2142	0.07	0.10	0.10	0.10
7/19/88	0025	0.15	0.15	0.14	--
	0305	0.10	0.11	--	--
	0906	0.03	0.04	0.03	--
	1320	0.20	0.20	0.20	--
	1543	0.15	0.13	0.15	0.15
	1800	0.14	0.10	0.13	0.15
	2310	0.25	0.22	0.22	0.24
7/20/88	0150	0.21	0.21	0.21	--
	0430	0.18	0.16	0.16	--
	0705	ND*2	ND	ND	ND
	0919	0.03	0.03	0.03	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.2

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: UPSTREAM

DATE	TIME	TRC TITRATIONS 1	2	3	4	5
8/15/88	1204	ND*2	ND	ND	--	--
	1446	ND	ND	--	--	--
	1658	ND	ND	--	--	--
	1950	ND	ND	ND	ND	ND
	2215	ND	ND	ND	--	--
8/16/88	0022	ND	ND	ND	--	--
	0218	ND	ND	ND	ND	ND
	0414	ND	ND	ND	--	--
	0614	ND	ND	ND	--	--
	0825	ND	ND	--	--	--
	1017	ND	ND	--	--	--
	1420	ND	ND	--	--	--
	1715	ND	ND	ND	--	--
	2042	ND	--	--	--	--
	2227	ND	--	--	--	--
8/17/88	0021	ND	--	--	--	--
	0223	ND	--	--	--	--
	0440	ND	--	--	--	--
	0620	ND	--	--	--	--
	0723	ND	--	--	--	--
	1110	ND	--	--	--	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = not detected; TRC <0.03 mg/l

APPENDIX 10.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: EFFLUENT

		TRC TITRATIONS				
DATE	TIME	1	2	2	4	5
8/15/88	1215	0.36	0.32	0.32	--	--
	1455	0.90	0.82	0.80	0.89	0.94
	1705	0.75	0.84	0.89	1.04	1.13
	2005	1.11	1.03	0.80	1.0	1.15
	2220	1.09	1.05	1.03	1.19	1.04
8/16/88	0030	0.79	0.77	0.71	0.65	0.70
	0223	0.64	0.56	0.60	0.65	0.70
	0420	1.10	1.07	1.00	0.91	--
	0618	1.36	1.37	1.20	1.39	--
	0830	1.60	1.57	1.50	1.52	--
	1029	0.84	0.74	0.64	0.80	--
	1430	0.54	0.53	0.51	0.51	0.50
	1725	0.52	0.87	0.85	--	--
	2047	1.10	1.12	1.16	--	--
	2230	0.74	0.78	0.79	--	--
8/17/88	0026	0.36	0.33	0.33	--	--
	0229	1.14	1.07	1.01	--	--
	0448	1.44	1.47	1.50	--	--
	0627	2.43	2.50	2.42	--	--
	0755	2.80	3.10	2.90	2.90	--
	0950	2.30	1.85	2.25	1.78	1.69

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985).

APPENDIX 10.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 8 m

DATE	TIME	TRC TITRATIONS 1	2	3	4	5	6	7
8/15/88	1246	0.11	0.07	0.06	0.10	0.14	0.12	0.11
	1507	0.33	0.26	0.35	0.27	--	--	--
	1720	0.30	0.36	0.26	0.43	0.37	--	--
	2015	0.52	0.49	0.50	0.48	0.52	--	--
	2230	0.46	0.45	0.46	0.50	--	--	--
8/16/88	0036	0.28	0.30	0.27	0.23	0.24	--	--
	0234	0.32	0.31	0.38	0.44	0.42	--	--
	0430	0.26	0.23	0.30	0.20	0.15	--	--
	0628	0.40	0.38	0.40	0.32	0.32	--	--
	0845	0.45	0.43	0.42	--	--	--	--
	1037	0.34	0.42	0.31	0.33	--	--	--
	1438	0.21	0.17	0.18	0.15	0.21	--	--
	1738	0.54	0.51	0.52	0.55	--	--	--
	2052	0.57	0.45	0.51	--	--	--	--
	2238	0.33	0.25	0.25	--	--	--	--
8/17/88	0031	0.13	0.13	0.17	--	--	--	--
	0234	0.39	0.34	0.40	--	--	--	--
	0455	0.61	0.51	0.51	--	--	--	--
	0636	0.65	0.67	0.81	0.71	--	--	--
	0807	0.78	0.82	0.88	--	--	--	--
	1030	0.49	0.45	0.51	--	--	--	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985).

APPENDIX 10.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 15 m

DATE	TIME	TRC TITRATIONS 1	2	3	4	5
8/15/88	1300	0.14	0.11	0.07	--	--
	1516	0.31	0.32	0.37	0.33	0.22
	1735	0.41	0.39	0.34	0.37	--
	2025	0.46	0.42	0.43	0.42	0.39
	2237	0.45	0.46	0.45	0.41	0.38
8/16/88	0047	0.24	0.27	0.24	0.24	0.24
	0240	0.30	0.24	0.20	0.16	--
	0440	0.28	0.26	0.25	0.30	0.27
	0638	0.40	0.40	0.40	0.40	0.39
	0855	0.32	0.23	0.15	--	--
	1050	0.36	0.34	0.36	--	--
	1510	0.17	0.33	0.22	0.20	0.21
	1754	0.52	0.43	0.42	0.49	--
	2058	0.51	0.48	0.48	--	--
	2242	0.28	0.23	0.26	--	--
8/17/88	0038	0.22	0.20	0.20	--	--
	0240	0.39	0.39	0.38	--	--
	0458	0.64	0.62	0.58	--	--
	0640	0.79	0.78	0.74	--	--
	0814	0.92	0.87	0.64	0.91	--
	1040	0.37	0.44	0.38	--	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985)

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 23 m

DATE	TIME	TRC TITRATIONS 1	2	3	4	5
8/15/88	1312	0.17	0.18	0.07	0.06	0.07
	1526	0.26	0.28	0.25	0.23	--
	1745	0.37	0.35	0.32	0.25	0.39
	2040	0.24	0.24	0.28	0.30	0.27
	2246	0.28	0.27	0.27	0.28	0.27
8/16/88	0057	0.20	0.19	0.19	0.22	0.21
	0255	0.13	0.17	0.17	0.19	0.22
	0448	0.18	0.18	0.20	0.18	0.20
	0647	0.27	0.27	0.28	0.25	0.25
	0905	0.03	0.02	ND*2	--	--
	1101	0.28	0.21	0.23	0.22	--
	1535	0.17	0.25	0.22	0.20	0.12
	1811	0.36	0.31	0.30	--	--
	2102	0.33	0.29	0.33	--	--
	2248	0.21	0.20	0.21	--	--
8/17/88	0042	0.11	0.12	0.12	0.12	--
	0244	0.26	0.29	0.27	--	--
	0503	0.38	0.36	0.39	--	--
	0647	0.56	0.49	0.48	--	--
	0825	0.75	0.72	0.55	0.53	--
	1045	0.27	0.23	0.25	0.25	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985)

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 30 m

		TRC TITRATIONS				
DATE	TIME	1	2	3	4	5
8/15/88	1320	0.06	0.06	0.06	--	--
	1540	0.24	0.26	0.24	--	--
	1800	0.28	0.26	0.21	0.21	--
	2045	0.17	0.17	0.19	0.17	0.18
	2255	0.19	0.19	0.18	0.15	0.17
8/16/88	0103	0.13	0.15	0.16	0.15	0.15
	0301	0.13	0.11	0.10	0.11	0.12
	0458	0.14	0.13	0.13	0.14	0.13
	0657	0.15	0.17	0.18	0.17	0.17
	0915	ND*2	ND	ND	--	--
	1107	0.26	0.21	0.15	0.16	--
	1552	0.19	0.11	0.15	0.13	--
	1819	0.24	0.19	0.20	0.21	--
	2112	0.12	0.17	0.21	--	--
	2253	0.15	0.13	0.13	--	--
8/17/88	0048	0.05	0.06	0.07	--	--
	0249	0.20	0.19	0.19	--	--
	0508	0.21	0.25	0.25	--	--
	0652	0.38	0.45	0.38	0.41	--
	0840	0.55	0.64	0.60	--	--
	1055	0.25	0.31	0.22	0.24	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of <u>Standard</u> <u>Methods</u> (APHA, 1985)

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 46 m

DATE	TIME	TRC TITRATIONS 1	2	3	4	5	6	7
8/15/88	1329	0.04	0.10	0.06	0.07	0.10	--	--
	1446	0.14	0.11	0.12	0.06	ND	0.11	--
	1658	0.18	0.15	0.15	0.14	--	--	--
	1950	0.18	0.17	0.19	0.24	0.23	--	--
	2205	0.24	0.22	0.24	0.22	0.26	--	--
8/16/88	0020	0.12	0.17	0.15	0.15	0.14	--	--
	0220	0.13	0.11	0.11	0.11	0.12	--	--
	0410	0.14	0.15	0.17	0.19	0.21	0.21	--
	0610	0.18	0.16	0.16	0.17	0.17	--	--
	0822	0.14	0.13	0.14	--	--	--	--
	1020	0.11	ND*2	ND	0.05	0.05	0.06	--
	1423	0.03	0.04	0.04	0.09	0.07	0.07	0.05
	1829	0.16	0.17	0.19	0.20	--	--	--
	2040	0.28	0.28	0.27	--	--	--	--
	2320	0.20	0.21	0.21	--	--	--	--
8/17/88	0020	0.06	0.02	0.10	0.12	0.12	0.10	--
	0222	0.28	0.28	0.29	--	--	--	--
	0445	0.28	0.30	0.30	--	--	--	--
	0620	0.46	0.46	0.47	--	--	--	--
	0740	0.46	0.44	0.41	0.43	--	--	--
	1028	0.24	0.22	0.23	0.25	0.24	--	--

*1: Total Residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 61 m

		TRC TITRATIONS				
DATE	TIME	1	2	3	4	5
8/15/88	1329	0.03	0.04	0.05	0.06	--
	1510	0.09	0.08	0.09	--	--
	1707	0.07	0.11	0.13	0.12	0.09
	2008	0.18	0.15	0.19	0.22	0.18
	2226	0.23	0.20	0.23	0.26	0.23
8/16/88	0028	0.11	0.11	0.11	0.11	0.10
	0230	0.80	0.80	0.80	0.80	0.80
	0420	0.15	0.16	0.16	0.15	0.17
	0620	0.13	0.13	0.13	0.14	0.14
	0830	0.12	0.13	0.13	--	--
	1040	0.04	0.05	0.06	0.06	--
	1455	0.06	0.07	0.06	--	--
	1842	0.15	0.15	0.14	0.14	--
	2040	0.22	0.23	0.21	--	--
	2240	0.14	0.15	0.13	--	--
8/17/88	0028	0.07	0.08	0.09	0.09	--
	0230	0.24	0.25	0.24	--	--
	0450	0.26	0.25	0.25	--	--
	0625	0.41	0.40	0.40	--	--
	0750	0.42	0.42	0.42	--	--
	1038	0.24	0.22	0.23	0.25	0.24

*1: Total Residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985).

APPENDIX 10.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME, TOTAL RESIDUAL CHLORINE (TRC)[*1]

STATION: 91 m

		TRC TITRATIONS				
DATE	TIME	1	2	3	4	5
8/15/88	1348	ND[*2]	ND	ND	--	--
	1520	ND	ND	ND	--	--
	1720	0.03	0.04	0.04	--	--
	2025	0.08	0.08	0.10	0.09	0.09
	2240	0.11	0.12	0.13	0.13	0.13
8/16/88	0040	0.05	0.05	0.05	0.04	0.04
	0238	0.03	0.03	ND	0.03	0.05
	0432	0.05	0.07	0.09	0.10	0.08
	0628	0.06	0.06	0.06	0.06	0.06
	0838	0.05	0.06	0.06	--	--
	1050	0.04	0.05	0.03	0.03	0.03
	1505	ND	ND	ND	ND	ND
	1854	0.12	0.09	0.09	--	--
	2052	0.11	0.12	0.10	--	--
	2242	0.06	0.06	0.05	--	--
8/17/88	0038	0.03	0.05	0.04	--	--
	0240	0.13	0.14	0.13	--	--
	0455	0.16	0.15	0.16	--	--
	0630	0.26	0.26	0.26	--	--
	0802	0.26	0.21	0.24	0.24	--
	1046	0.09	0.10	0.10	--	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985)

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 122 m

DATE	TIME	TRC TITRATIONS 1	2	3	4	5
8/15/88	1405	ND*2	ND	ND	--	--
	1529	ND	ND	ND	--	--
	1729	0.02	ND	ND	ND	--
	2041	0.04	0.02	0.02	0.06	0.04
	2250	0.05	0.07	0.07	0.08	0.07
8/16/88	0050	0.03	0.03	0.03	0.02	0.02
	0250	0.03	0.03	0.03	0.03	0.02
	0445	0.02	0.02	0.06	0.05	0.05
	0640	0.04	0.04	0.05	0.05	0.04
	0847	0.03	0.03	0.04	--	--
	1102	0.02	ND	ND	ND	--
	1513	ND	ND	0.02	--	--
	1940	0.05	0.05	0.02	ND	--
	2100	0.06	0.06	0.07	--	--
	2253	0.04	0.03	0.03	--	--
8/17/88	0042	ND	ND	0.03	ND	--
	0245	0.08	0.10	0.10	--	--
	0505	0.10	0.11	0.11	--	--
	0638	0.21	0.21	0.22	--	--
	0814	0.18	0.15	0.16	0.15	--
	1054	0.06	0.05	0.04	0.04	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985)

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 183 m

DATE	TIME	TRC TITRATIONS 1	2	3	4	5
8/15/88	1539	ND*2	ND	ND	--	--
	1739	ND	ND	ND	--	--
	2047	ND	ND	ND	ND	ND
	2305	ND	ND	ND	ND	ND
8/16/88	0105	ND	ND	ND	ND	ND
	0258	ND	ND	ND	ND	--
	0455	ND	ND	ND	--	--
	0650	ND	ND	ND	ND	ND
	0855	ND	ND	ND	--	--
	1111	ND	ND	ND	--	--
	1520	ND	ND	ND	--	--
	1957	ND	ND	ND	ND	--
	2108	ND	ND	ND	--	--
	2300	ND	--	--	--	--
8/17/88	0050	ND	--	--	--	--
	0250	ND	ND	ND	--	--
	0510	0.03	0.04	0.04	--	--
	0643	0.07	0.10	0.09	--	--
	0824	0.07	0.06	0.07	--	--
	1102	ND	ND	ND	--	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985)

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.2 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

BELCHERTOWN WWTP - LAMPSON BROOK

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 244 m

DATE	TIME	TRC TITRATIONS 1	2	3	4
8/16/88	1526	ND*2	ND	ND	--
	2009	ND	ND	ND	ND
	2112	ND	--	--	--
	2308	ND	--	--	--
8/17/88	0055	ND	--	--	--
	0255	ND	--	--	--
	0515	ND	--	--	--
	0650	ND	ND	ND	--
	0830	ND	ND	ND	--
	1108	ND	ND	ND	--

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985)

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.3

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: UPSTREAM

DATE	TIME	TRC TITRATIONS 1	2
9/13/88	1120	ND*2	ND
	1315	ND	ND
	1558	ND	ND
	1753	ND	ND
	2010	ND	ND
	2230	--	--
9/14/88	0058	ND	ND
	0315	ND	ND
	0557	ND	ND
	0810	ND	ND
	1030	ND	ND

*1: Total residual chlorine in mg/l using Method 408C (Amperometric Titration) of Standard Methods (APHA, 1985)

*2: ND = Not detected; TRC <0.03mg/l

APPENDIX 10.3

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: EFFLUENT

		TRC TITRATIONS						
DATE	TIME	1	2	3	4	5	6	7
9/13/88	1130	1.30	1.28	1.30	1.30	1.34	--	--
	1326	1.25	1.29	1.27	1.27	--	--	--
	1555	1.07	1.00	1.01	--	--	--	--
	1742	0.90	0.91	0.91	--	--	--	--
	1950	0.55	0.59	0.58	0.49	0.55	0.58	--
	2230	0.44	0.35	0.37	--	--	--	--
	2317	0.48	0.41	0.40	0.43	0.38	0.36	0.39
9/14/88	0040	0.59	0.56	0.57	--	--	--	--
	0255	0.88	0.92	0.92	--	--	--	--
	0420	1.15	1.12	1.08	1.09	--	--	--
	0540	1.50	1.46	1.31	1.39	--	--	--
	0757	0.46	0.45	0.42	--	--	--	--
	1020	0.66	0.57	0.61	--	--	--	--

*1: Total residual chlorine in mg/l using Method 407C (Amperometric Titration) of Standard Methods (APHA, 1985).

APPENDIX 10.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 15 m

DATE	TIME	TRC TITRATIONS 1	2	3	4	5
9/13/88	1138	0.21	0.17	0.19	0.14	0.20
	1333	0.28	0.27	0.27	--	--
	1609	0.18	0.17	0.19	0.16	--
	1803	0.16	0.14	0.15	0.14	--
	2015	0.17	0.17	0.20	0.16	--
	2245	0.04	0.05	0.05	--	--
9/14/88	0105	0.07	0.10	0.10	0.07	0.10
	0320	0.08	0.03	0.05	0.05	--
	0435	0.03	ND *2	0.04	0.03	--
	0600	0.13	0.08	0.17	0.11	--
	0815	0.12	0.14	0.17	0.10	--
	1040	0.20	0.21	0.21	--	--

*1: Total residual chlorine in mg/l using Method 407C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 30 m

		TRC TITRATIONS					
DATE	TIME	1	2	3	4	5	6
9/13/88	1151	0.13	0.15	0.16	0.16	--	--
	1338	0.20	0.20	0.20	--	--	--
	1615	0.15	0.14	0.15	--	--	--
	1812	0.06	0.11	0.16	0.16	0.17	--
	2050	0.07	ND	0.03	0.05	0.03	--
	2255	0.07	0.03	0.03	0.07	0.03	0.05
9/14/88	0112	ND*2	ND	ND	ND	--	--
	0330	ND	ND	0.04	ND	ND	--
	0456	0.11	0.06	ND	0.06	0.07	ND
	0610	0.16	0.22	0.30	0.37	0.15	0.11
	0835	0.03	0.18	0.04	0.11	ND	0.04
	1047	0.19	0.20	0.16	0.21	--	--

*1: Total residual chlorine in mg/l using Method 407C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 61 m

DATE	TIME	TRC TITRATIONS 1	2	3	4	5
9/13/88	1155	0.12	0.09	0.12	0.15	0.16
	1345	0.17	0.15	0.17	0.18	--
	1620	0.11	0.12	0.12	--	--
	1819	0.12	0.11	0.07	0.09	--
	2100	0.05	0.07	0.07	0.05	--
	2310	0.04	0.06	ND	0.07	0.05
9/14/88	0125	ND *2	ND	ND	--	--
	0335	ND	ND	ND	--	--
	0447	ND	ND	ND	ND	--
	0623	0.16	0.14	0.15	0.15	0.19
	0855	0.04	ND	ND	ND	--
	1100	0.17	0.13	0.13	--	--

*1: Total residual chlorine in mg/l using Method 407C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 91 m

DATE	TIME	TRC TITRATIONS 1	2	3	4	5
9/13/88	1205	0.08	0.10	0.10	0.11	--
	1352	0.15	0.16	0.16	--	--
	1627	0.08	0.09	0.10	0.10	--
	1826	0.11	0.11	0.10	--	--
	2110	0.07	0.06	0.05	--	--
	2302	ND*2	0.03	ND	0.03	ND
9/14/88	0112	0.03	ND	ND	ND	--
	0328	ND	ND	ND	--	--
	0440	ND	ND	ND	--	--
	0616	ND	ND	ND	--	--
	0901	0.07	0.04	0.06	ND	--
	1105	0.11	0.09	0.11	--	--

*1: Total residual chlorine in mg/l using Method 407C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 122 m

		TRC TITRATIONS			
DATE	TIME	1	2	3	4
9/13/88	1213	0.06	0.07	0.09	0.08
	1324	0.11	0.12	0.11	--
	1600	0.04	0.05	0.06	--
	1832	0.07	0.07	0.04	0.07
	2120	ND *2	0.05	0.03	0.03
	2253	ND	ND	ND	ND
9/14/88	0104	ND	ND	ND	--
	0321	ND	ND	ND	--
	0609	ND	ND	ND	ND
	0906	0.05	0.04	0.03	--
	1115	0.12	0.10	0.11	--

*1: Total residual chlorine in mg/l using Method 407C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC)[*1]

STATION: 152 m

DATE	TIME	TRC TITRATIONS 1	2	3	4	5	6	7
9/13/88	1120	ND	ND	ND	—	—	—	—
	1328	0.14	0.14	0.15	—	—	—	—
	1605	0.06	0.08	0.08	—	—	—	—
	1754	0.08	0.08	0.08	—	—	—	—
	2017	0.08	0.06	0.04	0.04	0.03	0.04	ND
	2243	0.05	ND[*2]	ND	ND	—	—	—
9/14/88	0058	ND	ND	ND	—	—	—	—
	0315	ND	ND	ND	—	—	—	—
	0601	ND	ND	ND	ND	—	—	—
	0815	0.24	0.22	0.24	—	—	—	—
	1108	0.04	0.04	0.08	0.08	0.08	—	—

*1: Total residual chlorine in mg/l using Method 407C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 244 m

		TRC TITRATIONS					
DATE	TIME	1	2	3	4	5	6
9/13/88	1130	ND*2	ND	--	--	--	--
	1331	0.08	0.08	0.04	0.07	0.08	--
	1612	0.10	0.08	0.06	0.05	0.05	--
	1759	0.05	0.06	0.06	--	--	--
	2033	0.04	ND	ND	ND	0.03	ND
9/14/88	0830	0.29	0.30	0.22	0.33	--	--
	1100	0.08	0.03	0.08	0.06	--	--
	1200	0.08	0.11	0.13	0.13	--	--

*1: Total residual chlorine in mg/l using Method 407C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 427 m

DATE	TIME	TRC TITRATIONS 1	2	3	4	5
9/13/88	1145	ND *2	ND	--	--	--
	1402	ND	ND	--	--	--
	1630	0.03	0.03	ND	ND	--
	1810	0.04	0.05	0.05	--	--
	2052	0.03	ND	ND	ND	ND
9/14/88	0905	0.27	0.21	0.23	--	--
	0930	0.29	0.17	0.18	--	--
	1213	0.04	ND	ND	--	--

*1: Total residual chlorine in mg/l using Method 407C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l

APPENDIX 10.3 (CONTINUED)

1988 CHLORINE TOXICITY STUDY

HOPEDALE WWTP - MILL RIVER

TIME, TOTAL RESIDUAL CHLORINE (TRC) *1

STATION: 518 m

		TRC TITRATIONS				
DATE	TIME	1	2	3	4	5
9/13/88	1355	ND	ND	--	--	--
	1817	ND	ND	--	--	--
	2114	ND	ND	ND	--	--
9/14/88	0858	ND	ND	--	--	--
	0938	ND	ND	--	--	--
	1037	0.10	0.07	0.13	0.11	0.10
	1224	ND	0.03	ND	--	--

*1: Total residual chlorine in mg/l using Method 407C (Amperometric Titration) of Standard Methods (APHA, 1985).

*2: ND = Not detected; TRC <0.03 mg/l